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THE EFFECT OF NITROGEN PHOSPHORUS AND POTASSIUM ON CERTAIN VEGETABLE CROPS IN SOUTHERN ALBERTA

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THE EFFECT OF NITROGEN PHOSPHORUS AND POTASSIUM ON CERTAIN VEGETABLE CROPS IN SOUTHERN ALBERTA

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Department of Plant Science

A THESIS
submitted to the University of Alberta
to fulfil approximately one-half of the
requirements for the degree of
MASTER OF SCIENCE

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The undersigned hereby certify that they have read and recommend to the Committee on Graduate Studies for acceptance, a thesis on "The Effect of Nitrogen, Phosphorus, and Potassium on Certain Vegetable Crops in Southern Alberta", submitted by Ib L. Nonnecke, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

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INTRODUCTION

Commercial vegetable crops have become an important phase of agricultural production in Southern Alberta. Not only is the soil suitable for their production but also the growing season is such that several important staple vegetables can be raised successfully. This favourable situation could last indefinitely if it were not for an eventual deterioration of the physical structure and exhaustion of nutrient content of the growing medium. Virgin soils in the area have been rated as containing a medium supply of available nitrogen, a low supply of available phosphorus, and a high supply of available potassium (34).

Large irrigated areas are now being utilized for these crops and new lands are soon to be brought under irrigation owing to the development of the St. Mary's River project. Since these new lands cannot produce grain economically, the agricultural producer must turn to intensive crop production in order to obtain a reasonable rate of return. It would seem logical to assume that intensive crop production will soon deplete the soil, unless proper fertilizer treatments are employed. Consequently, the project reported herein was undertaken to determine the effect upon sweet corn, beans, lettuce, carrots, and cabbage yields as grown under irrigation in Southern Alberta, of combinations of major fertilizing elements.

LITERATURE REVIEW

General Effects of the Major Plant Food Elements

Nitrogen

Schreiner and Brown (27) present a statement regarding the effects of nitrogen on crop plants. They have stated that the presence of an adequate supply of available nitrogen in the soil is one of the most important factors relating to the maintenance or improvement of soil fertility. The lack of sufficient amounts of available nitrogen in soils, particularly those that have been cropped for many years, has long been a limiting factor in crop production. Plants supplied with sufficient nitrogen are much better able to utilize other nutrient materials such as phosphorus and potassium compounds. On the other hand, no amount of available phosphorus and potassium will overcome a deficiency of available nitrogen, it being generally recognized that one nutrient element cannot be substituted for another. An oversupply of available nitrogen in the soil tends to promote late maturity, poor seed development, makes plants more susceptible to disease organisms, because of the development of more succulent tissue, and is decidedly uneconomical.

Phosphorus

Pierre (23) in his summations regarding the merits of phosphorus as a plant nutrient, states that phosphorus has sometimes been called the master key of agriculture. Its importance

in general farming is acknowledged by the fact that low crop production is due more often to a lack of phosphorus than to the lack of any other element. He states further that most soils respond to additions of phosphorus fertilizers. It is apparent that a phosphorus deficiency becomes most evident after land has been farmed for a few to many years, especially under a grain or livestock system of farming.

Pierre states also, that of the three major fertilizing elements, phosphorus seems to affect the other two major elements the least, and yet its behaviour on plants in turn is greatly influenced by the presence of the other two elements in varying and sometimes highly specific ratios.

Potassium

Unlike nitrogen and phosphorus the quantity of potassium found in most soils is comparatively high. Cooper *et al* (3) in summing up the place of potassium in our farming program state that without sufficient available potassium in the soil, crop plants suffer reduced vigor and quality, greater susceptibility to disease, and impairment of growth processes. On the other hand, the presence of an adequate supply of available potassium in the soil promotes health and improves the quality of the plant, insures greater efficiency in photosynthesis, increases resistance to certain diseases, offsets the effects of an oversupply of nitrogen, and helps the plant to utilize soil moisture more advantageously, particularly during periods of drought.

Cooper et al (3) state further, that potassium is intermediate between nitrogen and phosphorus in its effects on plant growth. It tends to slow down the effects resulting from excessive nitrogen and to prevent too rapid maturity often induced by too much available phosphorus. It is evident, therefore, that the application of available potassium compounds to the soil or the employment of practices tending to make the unavailable potassium compounds of the soil available, is particularly important to the maintenance of soil fertility and to the production of crops of high quality.

A review of experimental results from the Dominion Experimental Station at Lethbridge (34) indicates that considerable response to nitrogen and phosphorus fertilizer combinations have been obtained with sugar beets, certain cereals crops, and potatoes. However, no response has been recorded from the application of potassium to any crop. There is no reference in Western Canada dealing with the effects of nitrogen, phosphorus, and potassium on the five vegetable crops studied in this experiment.

Major Element Effects on Specific Vegetable Crops

Sweet Corn

Sweet corn can be successfully raised on a wide variety of soils (33). Most workers substantiate this statement. However, differences of results and opinions occur as to amounts and combinations of the nutritional elements required for sweet corn

production. Thompson (33) found sweet corn to be a heavy feeder but it was not necessary to fertilize heavily under average conditions. Work (37) agrees in part with Thompson, but states further that as a crop, it responds generously to liberal applications of organic matter and nutrients. Huelsen and Gillis (15) appear to state the nutritional requirements of the sweet corn plant more critically than any other authors reviewed. They found that sweet corn is rather specific in its plant food requirements and it responds well to fertilizers only when the proper ratios of nitrogen, phosphorus, and potassium are used.

Those workers who have studied the placement of fertilizers with sweet corn, agree that contact placement of seed and fertilizers is hazardous. Shoemaker (29) noted that germination and root growth may be retarded when fertilizer is applied with the seed. He states that desirable effects of fertilizer on early growth, maturity, and yield are in proportion to the development of the roots. These observations agree with the results of Smith (31) on the same crop. Stanford and Nelson (32) working on corn with radio-active superphosphate, showed that the percentage of phosphorus derived from a fertilizer is influenced by the position of the fertilizer in respect to the seed. Placement of the fertilizer at seed depth and in bands on one or both sides of the seed, generally resulted in a greater utilization of the applied phosphorus by the plant, than placement in a single band three inches below the seed. Increases in yield of the total dry matter of the above-ground portions of the plant particularly

during the early stages of growth, also showed that the seed-level placement was superior to either of the other two methods. The greatest disagreement regarding the fertilizer requirements of sweet corn arises when the actual plant needs are determined.

Huelsen and Gillis (15), working in Illinois under soil conditions where phosphorus is the limiting factor, found that sodium nitrate applied as a side dressing without an accompanying basal treatment of the other minerals, produced variable results in yields, ranging from decided decreases to definite increases, and therefore such a soil treatment was considered to be unreliable for sweet corn when used alone. However, Williamson (36) working under somewhat similar soil conditions in Alabama, recommended that nitrate of soda was the only fertilizer of any value in sweet corn production.

In view of the phosphorus deficient conditions encountered by Huelsen and Gillis (15), heavy applications of phosphatic fertilizers were expected to give corresponding increases in yield. Their results, however, were contrary to expectations. It was only when nitrogen was combined with the phosphatic fertilizers that larger amounts of phosphorus could be utilized by the sweet corn plant, resulting in higher yields. Potassium caused a similar response to that of nitrogen in the utilization of phosphorus.

Bushnell (1) after sixteen years of study, found that sweet corn thrived without any phosphate fertilizer. This is explained in part by the findings of De Turk (7) at Illinois, which indicated that sweet corn can quite readily remove phosphates from the soil. However, where high yields are in demand

it is necessary to supplement the soil with superphosphate. Because sweet corn also has a high potassium requirement, De Turk points out that the supplementing fertilizer must contain potash as well. Further work by Bushnell (2) indicated that increases from potash fertilizer alone were significantly greater than the unfertilized plots. Huelsen and Gillis, already cited, came to the conclusion that use of potash alone as a sweet corn fertilizer could not be recommended, as there was evidence in their findings that even small amounts acted unfavourably on yields, unless accompanied by nitrogen and phosphorus. No reasons for this reaction were advanced.

The last mentioned workers found, when combining all three major plant food elements, that the only ratio that would give significant results was a 1-2-2 ratio. Any variation of a single element from this formula caused reduced yields or at best highly variable results. Prince and Blood (24) working under different soil conditions than Huelsen and Gillis found that by increasing the amounts of fertilizer from 500 to 1,000 pounds of either a 1-2-1 or a 1-4-1 ratio, an increase of approximately one ton of sweet corn ears per acre resulted. The greatest net profit from any treatment, their findings showed, was from the use of 1,000 pounds of the 1-2-1 ratio. They noted further that with small amounts of fertilizer, a high phosphorus formula proved to be slightly superior, but when large amounts were used the choice of formula became less important.

Olsen and Brooks (21) working with sweet corn on an acid soil, found that the greatest increases in yield were caused

by the nitrogen application. Although phosphoric acid and potash were used they were not very effective. In another experiment Olsen and Bledsoe (20) reported that it is questionable that even a small amount of phosphorus or potassium would be effective.

These rather varying and conflicting findings may be attributed to the varying soil types and the response to fertilizers by sweet corn. Thompson (33) suggests that temperature during the formative period of the ears is of major importance in nutrient uptake. One might suggest, too, that varietal difference in ability to forage might account for some of the confliction described.

Beans

Shoemaker (29) states that bush beans yield best on a fairly fertile soil. A very rich soil is not desirable since too much vine growth will be produced at the expense of pod production.

The placement of fertilizers with most legumes is of utmost importance and beans are no exception. Thompson (33) states that many experiments have shown it is unsafe to apply fertilizers in the row in contact with the seed as the beans seem very susceptible to fertilizer injury. Cumings *et al* (5) working with this problem recommend that placement of fertilizer in bands two inches to each side of the seed row, one and one-half inches below the level of the seed was the most satisfactory fertilizer placement under the conditions of this experiment. Placement at three inches below the seed, they found produced good results, but was

Sayre and Clarke (25) studied the rate of solution and the movement of different fertilizers in the soil, and the effects of fertilizers and the germination and root development. They found that there is considerable movement of fertilizer solution upward and downward. The inorganic nitrogen and potassium fertilizers had very rapid rates of dissolution thus reducing the germination of seed planted in contact with the fertilizer band. None of the nitrogen and potassium fertilizers stimulated root growth directly in the fertilizer band.

Miller et al (18) found that beans do not respond like most other crops to applications of plant nutrients in the form of commercial fertilizers. There is little doubt that the response of beans to fertilizers is often nullified by adverse weather conditions during the period of blooming and setting of pods. It was observed generally by them that the plants on fertilized plots during the early part of the growing season made much better growth than did those on the unfertilized plots, but that they failed to give correspondingly increased yields. Miller points out that some investigators have suggested that this was due to moisture conditions and water requirements. When the soil moisture content is low during the blooming period the greater vegetative growth on the fertilized plots causes a greater demand for water by the leaves and there is not sufficient for a maximum set of pods. On the unfertilized plots, on the other hand, a smaller demand for water by the leaves of the smaller plants might allow a greater set of pods. An equalization of yields would then result despite the

not so practicable as side placement. Sayre and Cumings (26) working with peas came to similar conclusions. Table 1 illustrates their data.

Table 1. Effect of Placement on Pea Yields (26)

Fertilizer Amounts	Placement	Yield pounds per acre
300 lb., 4-16-4	1½ inches to side 1 inch rows	2,401
"	2½ " " " " " "	2,877
"	3½ " " " " " "	2,274
	With seed	935
Unfertilized		2,246

The fertility requirements of beans seem to be much more uniform, regardless of location, than those of sweet corn. Ware (35) found that the response to phosphorus was much greater than any other major fertilizing element. Ware states further that although beans belong to a group of plants which may fix nitrogen symbiotically, yields were greatly increased by the application of nitrogen. The percentage of early beans was reduced by the addition of nitrogen but the increase of the total crop was very marked. Shoemaker (29) agrees with the findings of Ware but states further that yields are often increased by application of nitrogen when the soil is low in nitrogen-fixing bacteria. Also he states that beans frequently show an outstanding response when supplied with a fertilizer that contains a relatively high proportion of phosphoric acid. Thompson (33) has shown that for quick maturing varieties, especially when they are planted early in the season, some readily available nitrogen is required.

greater vegetative growth prior to the blooming period. The early response to fertilizers has led many to place a false value on the benefits of fertilizing beans.

Lettuce

The lettuce plant is a relatively poor forager with a small root system and consequently surface soil should be well supplied with available nutrients (33). On sandy soil Thompson (33) found that a fertilizer for lettuce should contain a 1-2-1 or 1-3-1 ratio of the major elements.

Griffiths (13) found under alkaline soil conditions that ammonium phosphate (11-48-0) gave the highest total yields of lettuce on land receiving ten tons of manure per acre. On land receiving no manure, he states, the simple organic fertilizers gave best results.

Crider (4) also working with an alkaline soil applied fertilizers just prior to planting time with the exception of sodium nitrate which was applied as a side dressing later. He found that acid phosphate (P_2O_5) produced the only marked response. The effects of the phosphates were evident when used alone and also with other fertilizers. Acid phosphate and blood meal produced outstanding results when used in content up to eleven per cent nitrogen, above which maturity was retarded. The use of nitrogenous fertilizers alone without acid phosphate produced no increase in size of foliage over unfertilized plots.

Work (37) suggests that lettuce soils should be high in organic matter and recommends a 1-4-2 ratio of the major elements as an adequate fertilizer. He points out the dangers of over-fertilizing, which may lead to rapid growth and possible damage from tip-burn.

Schroeder and Wittmer (28) working with pot cultures employing four levels of calcium and four levels of nitrogen, found that each element was essential to the other for correct fertilizer requirements. They concluded that yields of lettuce were more dependent upon additions of calcium than additions of nitrogen.

McGeorge et al (17) studied the fertilizing of lettuce on calcareous soils from several aspects. They found that phosphates hasten maturity and increase compactness and yield of marketable heads per acre. When phosphates were combined with nitrogen a slight delay in maturity occurred. It was further shown that any of the readily available forms of phosphorus either alone or in combination with nitrogen were beneficial.

These workers also studied the effect of the crop on the soil during development. Although the crop made a heavy initial demand on the soil for plant food a comparison between unfertilized plots and fertilized plots showed a continuous withdrawal of nitrogen, phosphorus, and potassium throughout the growing period. The heaviest heads were produced on the soil initially highest in available phosphorus. The greatest increase in heads was from phosphate fertilizers on the phosphate deficient plots. Weights

of heads increased with remarkable regularity with increases in available phosphates.

Carrots

Thompson (33) considered the carrot to be "hard on the land" probably because of its observed heavy use of potash. He states further that root crop fertilizers should be relatively high in phosphorus especially on non-manured lands and recommends a 1-4-1 ratio of the major fertilizer elements.

Hartwell et al (14) in their experiments with several truck crops came to the conclusion that carrots respond poorly to soi phosphates;i.e. they do not seem successful in supplying their needs from the soil itself. Work (37) simply recommends for root crops in general that on heavy soils a 1-4-1 ratio of the major fertilizing elements be used with manure and on lighter soils a 1-2-1 ratio. This is in general agreement with the findings of Thompson and Hartwell.

Cabbage

There seems to be more agreement among workers from various locations as to the fertilizer requirements of cabbage than exists for any of the other vegetable crops. The fact that it responds similarly under a great variety of soil and climatic conditions is striking.

Cabbage is considered a gross feeder and therefore hard on the soil (33). Also it has been found that it makes rapid res-

ponses to favourable conditions. High quality in a given variety is closely associated with quick growth. Both well rotted manure as compost and commercial fertilizers may be liberally used to advantage (29).

Fite (8) describes a good cabbage soil as being friable and loamy, rich in humus, and nitrogen. He found that under alkaline soil conditions ammonium sulphate produced highest yields and that phosphoric acid produced no great increase in yield. Potassium he noted as also having little influence on yield. Shoemaker (29) presented some evidence that cabbage takes up several times as much sulphur as phosphorus from the soil. Fite (9) in a later experiment found that on depleted soils superphosphate might be a profitable fertilizer to use in combination with nitrogenous fertilizers.

Parker (22) working on an acid limestone soil of only fair fertility found that for good cabbage production, phosphorus was a limiting factor in that a sufficient amount of phosphorus increased the amounts of nitrogen and potassium that could be utilized advantageously by the plant.

Moore and Campbell (19) also working on an acid soil showed that by varying the amounts of nitrogen, phosphorus, and potassium in a cabbage fertilizer, greatest increases came from nitrogen. As the nitrogen was increased the yield and profits were correspondingly increased. Increasing the amount of phosphorus up to twelve per cent also gave increased yield and profit. The potassium variations resulted in little difference in yield.

Bushnell (1) also working on an acid soil found that the

nitrogenous fertilizer proved to be particularly necessary for cabbage. He observed that phosphorus and potassium had little effect on the yield of cabbage.

Gourley and Magruder (11) found that cabbage requires nitrogen more than it requires phosphorus for maximum production. Zimmerly and Parker (38) studied the value of different nitrogenous fertilizers. They found that nitrate of soda and sulphate of ammonia used together gave higher yields and heads of better quality than were secured where either was used alone as a source of nitrogen.

DESCRIPTION OF EXPERIMENTAL AREA

Soil

The experiment was laid out on dark brown prairie soil at the Dominion Experimental Station, Lethbridge. The soil was uniform throughout the experimental area. Its physical characteristics, described as a heavy silt loam, are typical of the area immediately surrounding Lethbridge. The Spurway quick soil test method showed that the plot soil contained 12 ppm. of available nitrates, 1 ppm. of available phosphates, and 20 ppm. of available potash, thus indicating the nutrient composition of the soil at the outset of this experiment. This is representative in a general way of the nutrient content of irrigation soils in Southern Alberta.

A soil reaction test of the plot area revealed a pH of 7.8 which is typical for the alkaline nature of the soils in the region.

History of Plot Area

During the two years prior to the beginning of this experiment, the plot area was used in the production of mangels from which heavy yields were harvested. The mangels had been fertilized with approximately 50 pounds of ammonium phosphate (11-48-0) per acre, which was considered sufficient only for the current crop needs. Preceding the mangels, alfalfa had been grown on this area, in order to lessen a serious infestation of field bindweed.

MATERIALS AND METHODS

Materials Used

Five recommended vegetable kinds representing species of the major cultural groups were selected for use in this study. The selections were as follows:

Sweet Corn - Golden Early Market
Beans - Round Pod Kidney Wax
Lettuce - New York #12
Carrots - Red Cored Chantenay
Cabbage - Danish Ballhead

All vegetables were grown in 18 foot rows 22 inches apart. The lettuce and cabbage plants were transplanted from the cold frames to the rows, 14 and 18 inches apart respectively. Sweet corn, carrots and beans were sown directly into the rows. The sweet corn was thinned to one plant every foot, the carrots to one plant every 2 inches and beans to one plant every 4 inches.

The fertilizer treatments were combined in an approximate 1-4-1 ratio which was based upon the nitrogen-phosphate ratio in the widely used ammonium-phosphate (11-48-0) fertilizer. Since the rates of application were so arranged as to supply nitrogen and phosphate in amounts equivalent to an application of 200 pounds per acre of ammonium-phosphate, it was necessary to use the following combination of materials; N from ammonium sulphate (21-0-0); P from triple superphosphate (0-43-0); and K from muriate of potash (0-0-50). However, it was necessary to use the mono-calcium phosphate in order to have a single form of phosphate in the experiment which was made up of the following treatments.

NPK
N
P
K
NP
PK
NK
nil

The method of application was as follows: seven-eighths of the fertilizer was divided into two parts and applied in side bands 1½ to 2 inches on either side of the row and 1 inch below the level of the seed or plant just prior to seeding or transplanting, so as not to disturb the soil. The remaining one-eighth of the fertilizer was applied directly with the seed or transplant. This method of fertilizer placement was used because previous experimental results at Lethbridge (34) especially with sugar beets had indicated that this was beneficial in starting plants quickly in the spring. Application of fertilizers was made with a rod-row V-belt grain seeder.

Plot Arrangement

A simple randomized block design with three replications of each treatment for each vegetable was used. A plot consisted of 4 rows, each row being 18 feet long and 22 inches apart. The 2 centre rows were regarded as the sampling unit and the 2 outside rows were treated as guard rows. Each plant in the 2 centre rows was considered part of the sampling unit for yield purposes. The same plot was used throughout the experiment for each treatment. Fig. 1 shows the general layout of the experimental plot.

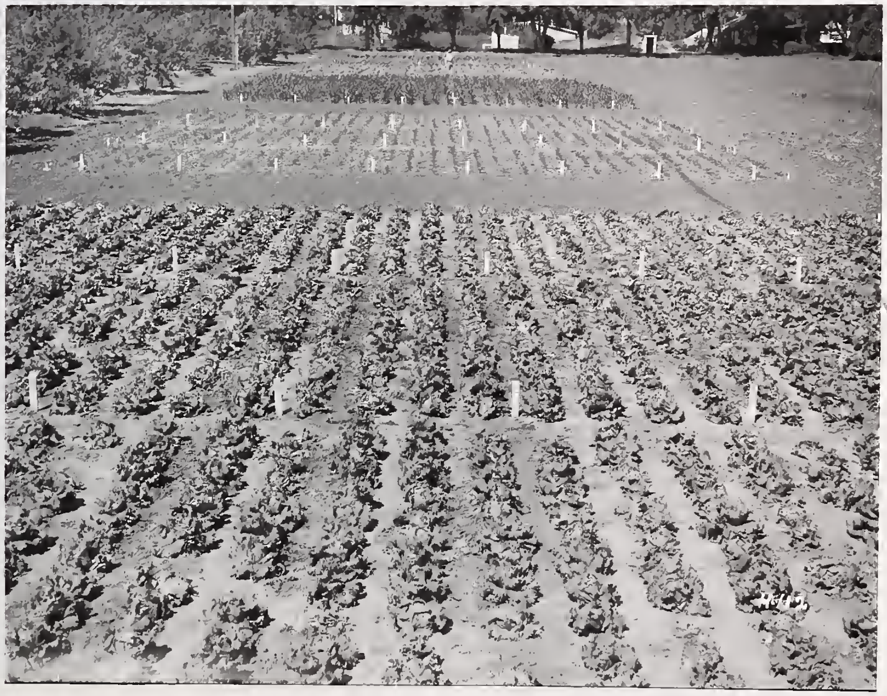

Fig. 1. A general plan of the experimental area showing lettuce plots in the foreground.

Cultural Methods

Each variety was given the optimum growing conditions insofar as was feasible. Weeds were kept at a minimum to prevent competition with the vegetable plants for the fertilizers. The number of irrigations varied from year to year and water was applied whenever it was considered that any particular crop required moisture. During 1949 a sprinkler system was used making it possible to apply a more uniform irrigation to all plots, whenever required, than had been possible in the previous years. The soil crust formed by the irrigation water was broken and pulverized as soon as possible after each irrigation.

Methods of Collecting Data

Each kind had to be harvested differently. The methods employed are described below.

Sweet Corn

The first harvest was taken when any one plot had 5 or more marketable ears, with successive harvest being made as the ears matured. The thumb-nail method of ascertaining maturity was used. Weight and number of ears at each harvest were recorded.

Beans

The bean plots were harvested when any one plot had reached maturity; i.e. when the pods were just fully coloured yellow and snapped cleanly in two when broken between the fingers. Weight of each harvest was recorded.

Lettuce

The first harvest was taken when any one plot had 4 heads considered to be mature; firmness and size of heads being the criterion of maturity. Successive harvests were made as the heads matured. Weight and number of heads obtained at each harvest were recorded.

Carrots

The carrots were grown until the roots had reached maturity and were ready for winter storage. At that time a single harvest was made and the total weight was recorded.

Cabbage

The cabbages also were left until the heads were ready for winter storage. A single harvest was made and a record of weight and number of heads were kept.

General Since each plot was sufficiently small, the entire two centre rows were harvested for data records on all crops.

Methods of Analysing Data

The data were divided into two parts, to determine the effect of the three major elements on yield and maturity. The effect on yield was analysed statistically (12) using the analysis of variance. Where significant differences occurred the mean standard error was obtained for comparative purposes. The analysis of variance/was applied to the yields by years as well as to the mean three-year results.

The effect on maturity was based on a comparison of number of heads and weight of produce at first and last harvests.

The effect of the individual elements on the mean yields (1947-49) was analysed by pairing and significance was tested by the "t" test. The complete detail of analytical methods is found in an appendix to this report.

Climatic Influences

Before a true evaluation of the results can be made, the possible influence of the weather should be noted. The years 1947 and 1949 were considered normal with several irrigations being necessary. However, the start of the 1948 growing season was characterized by unusually heavy and frequent rainstorms. It was the type of spring associated with much potassium leaching (3) from the upper soil surfaces, forcing many plants normally satisfied by the potassium content of the soil, to utilize whatever potassium was available. In this experiment the most readily available form of potassium was assumed to be that which had been placed in bands near the seed row or directly with the seed.

RESULTS

1. Effects of Fertilizer Combinations on Vegetable Yields

Sweet Corn

The yield obtained in 1947 from the replicates were variable indicating possible soil heterogeneity. Although yields from only two treatments were lower than check, there were no yields significantly higher. One of the treatments averaging lower in yield than the "no treatment" plots was that whereon the "complete" fertilizer was used. Table 2 shows the yields together with means for treatment and replicates. The greatest response was from phosphorus-potassium and phosphorus.

Table 2. Sweet corn yields in pounds of ears per plot for 1947

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	18.3	25.9	25.5	23.2
N	24.9	26.4	23.4	25.0
P	26.9	22.9	29.2	26.3
K	31.8	17.2	23.5	24.2
NP	24.0	27.2	23.9	25.0
PK	28.6	27.7	25.1	27.1
NK	27.0	17.6	30.1	24.9
nil	30.9	18.2	25.1	24.7
Mean	26.4	22.9	25.7	

F value (treatment) 0.2

The results for 1948 showed that the treatments were more effective in 1947. The yields are recorded in Table 3. The analysis of variance indicated that significant differences due to the treatments occurred. Phosphorus was no longer beneficial;

on the contrary, where used alone this element seemed to have a depressing effect on the yields of sweet corn. The nitrogen and potassium treatments produced the greatest yield responses. Despite the nonbeneficial effect of phosphorus alone the combined phosphorus-potassium treatment resulted in a significant yield increase.

Table 3. Sweet corn yields in pounds of ears per plot for 1948

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	28.8	26.5	31.0	28.8
N	30.0	29.2	31.0	30.0 *
P	22.5	20.3	18.8	20.6 *
K	28.0	31.2	36.5	31.9 *
NP	27.5	27.5	29.0	28.0
PK	30.0	29.2	30.2	29.8 *
NK	28.8	26.5	32.8	29.3
nil	25.8	25.5	28.0	26.4
Mean	27.4	27.0	29.9	

F value (treatment) 9.5**

The minimum significant difference for treatment was ±3.1 pounds.

* Significant difference (5% level)

The relatively high yields due to potassium are particularly interesting since no previous record of response to potassium by any crop had previously been recorded in Southern Alberta (34). Figures 2,3 and 4 illustrate some of the effects on sweet corn caused by the fertilizers about six weeks before harvest.

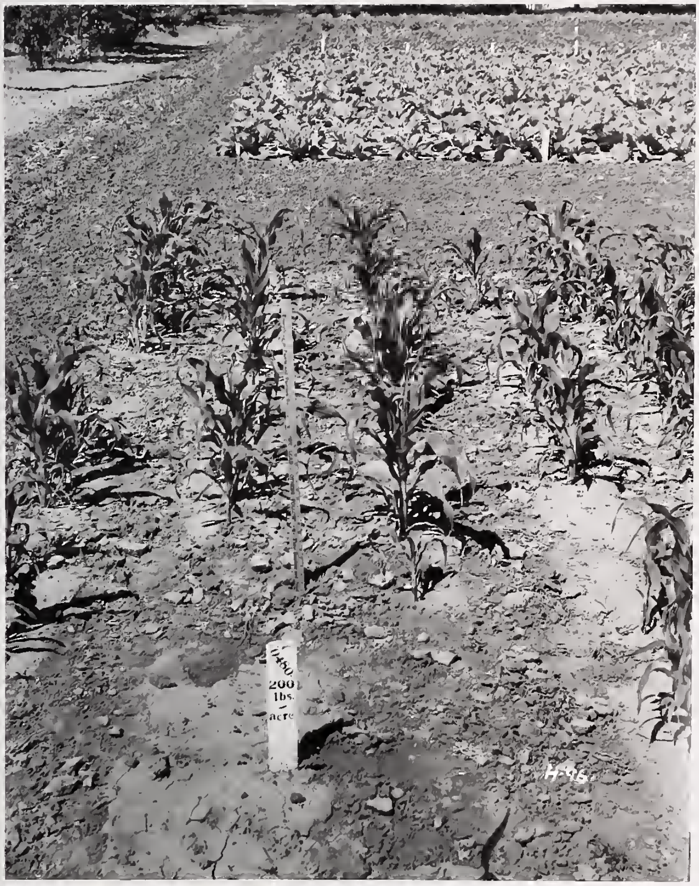

Fig. 2. The effect of phosphorus on sweet corn 1948

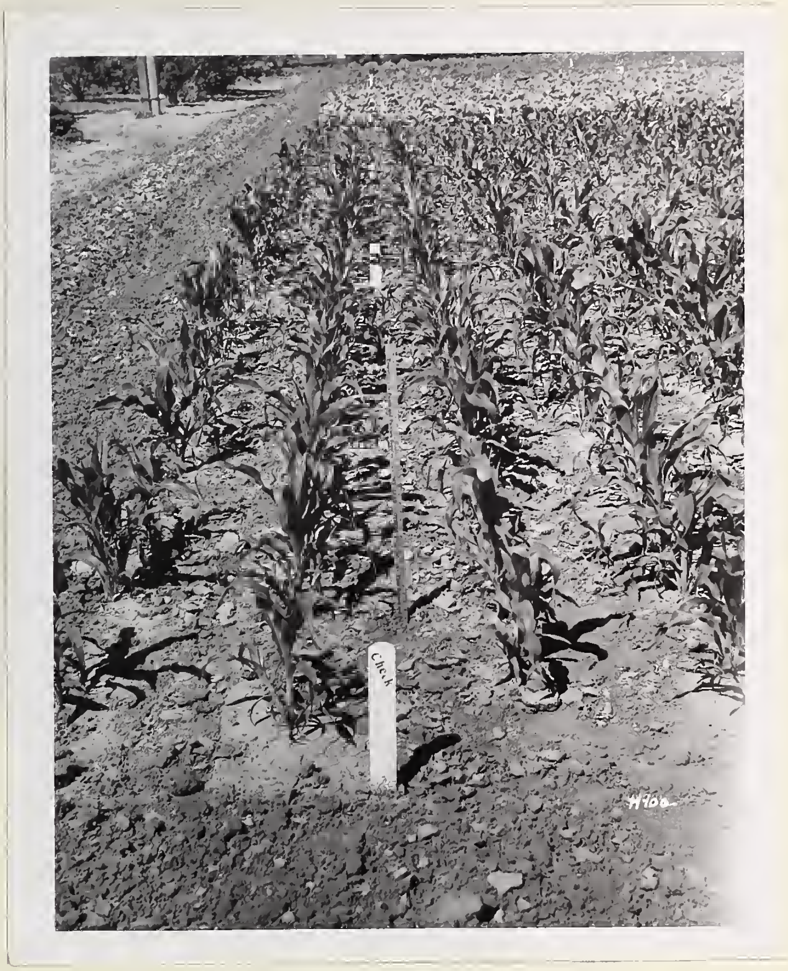

Fig. 3. The effect of no fertilizers on sweet corn 1948

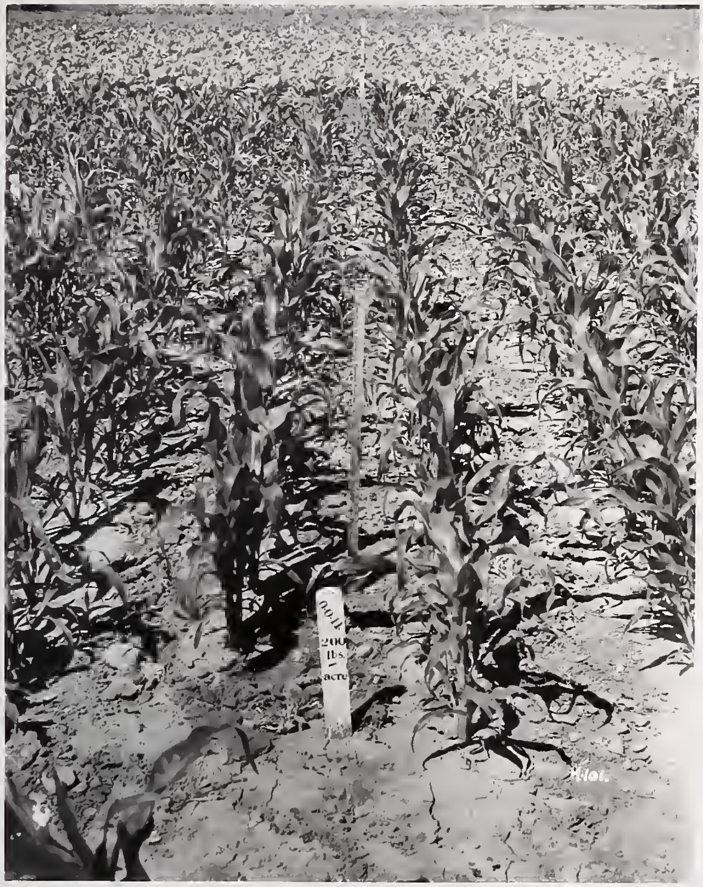

Fig. 4.The effect of potassium on sweet corn 1948

The effect of the treatments in 1949 was not nearly so outstanding as in 1948. More of the fertilizer treatments were significantly different from each other than before but only at the five per cent level of significance. These yields are indicated in Table 4. Although nitrogen and potassium were again significantly higher than check the highest yields came from a combination of elements,namely phosphorus-nitrogen,

nitrogen-potassium and the complete fertilizer nitrogen-phosphorus and potassium. Plots receiving phosphorus alone, however, did not yield less than the unfertilized plots as was the case in 1948. The favorable effect shown by phosphorus-potassium application in 1948 was not repeated in 1949.

Table 4. Sweet corn yields in pounds of ears per plot for 1949

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	25.8	23.6	24.3	24.6 *
N	25.4	25.8	18.7	23.3 *
P	19.6	20.0	19.1	19.6
K	21.8	24.4	21.6	22.6 *
NP	21.7	21.6	27.1	26.4 *
PK	18.0	17.7	19.2	18.3
NK	26.2	22.8	26.0	25.0 *
nil	17.7	19.6	19.1	18.8
Mean	22.0	21.9	21.9	

F value (treatment) 4.3 *

The minimum significant difference for treatment was ± 2.23 pounds.

* Significant difference (5% level)

Figures 5, 6 and 7 show the sweet corn plots in 1949 indicating somewhat different treatment effects than in 1948. These photographs were taken approximately four weeks before harvest.

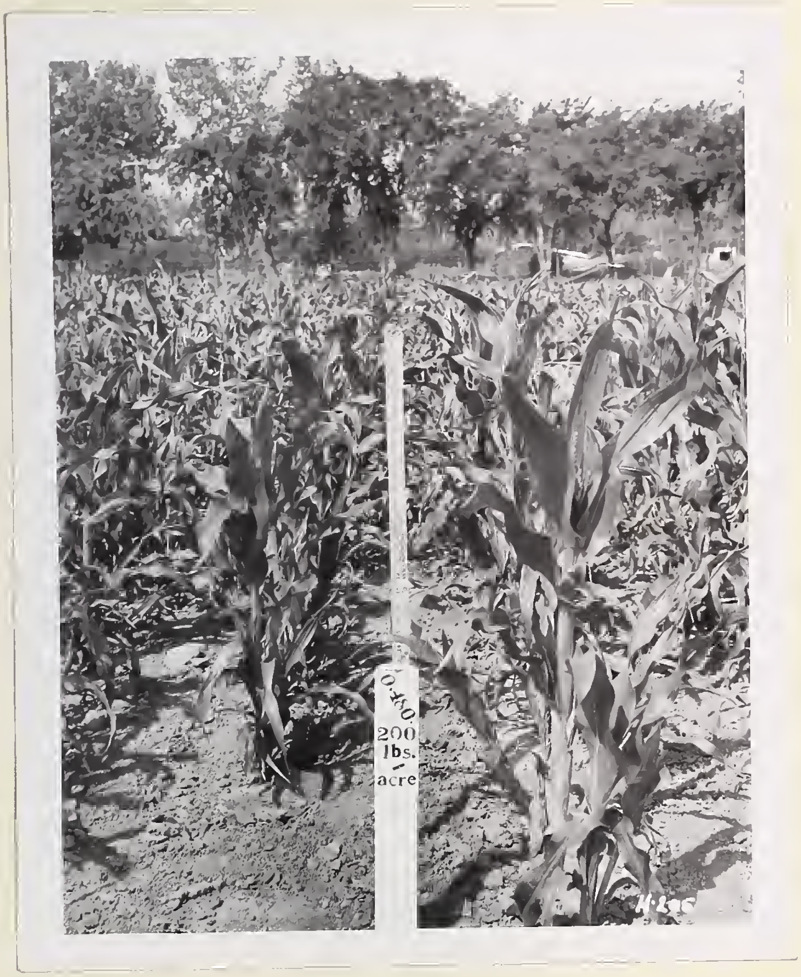

Fig. 5. The effect of phosphorus on sweet corn 1949

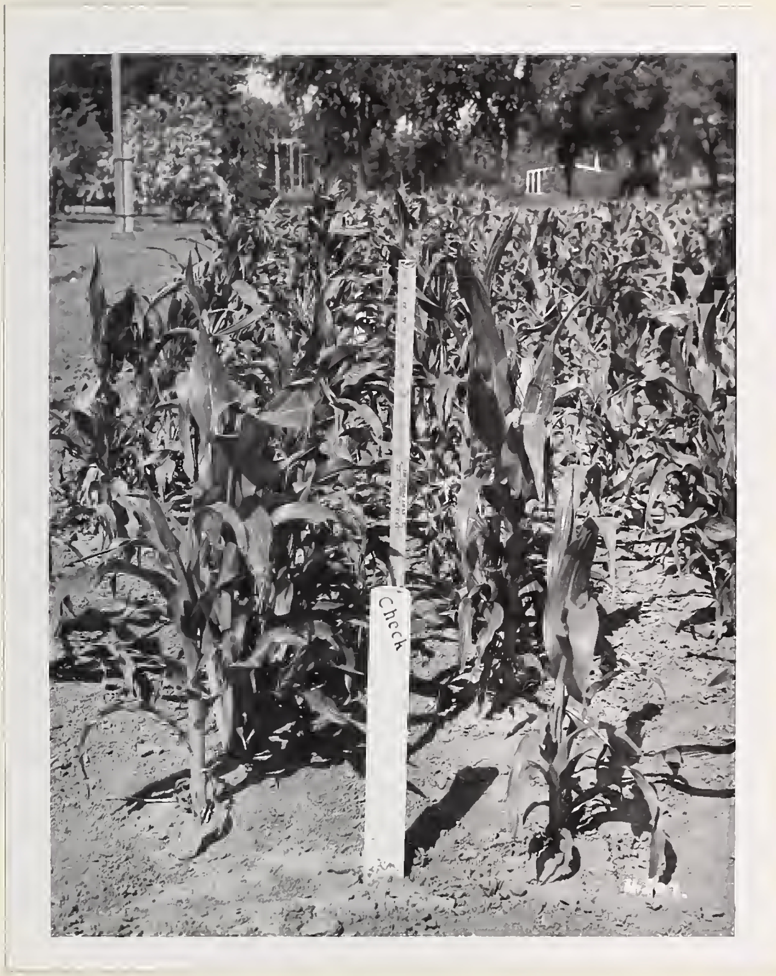

Fig. 6. The effect of no fertilizer on sweet corn 1949

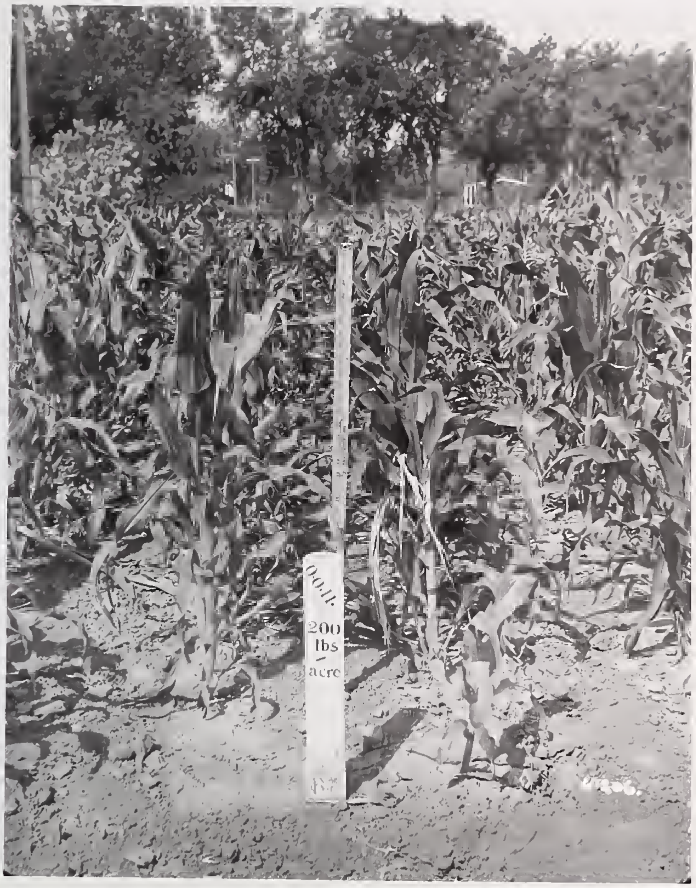

Fig. 7. The effect of potassium on sweet corn 1949

The mean yields for the three years indicated no significant diferences due to any one treatment. Only phosphorus produced a lower yield than the check, all other yields being higher. The mean yields for the three years are presented in Table 5.

Table 5. The Mean Yields of Sweet Corn in Pounds - 1947-49

Treatment	1947	1948	1949	Mean
NPK	23.2	28.8	24.6	25.5
N	25.0	30.0	23.3	20.1
P	26.3	20.6	19.6	22.1
K	24.2	31.9	22.6	26.2
NP	25.0	28.0	26.4	25.4
PK	27.1	29.8	18.3	25.0
NK	24.9	29.3	25.0	26.4
nil	24.7	26.4	18.8	23.2
Mean	25.0	28.1	22.0	

F value (treatment) 1.0

The influence of the individual elements on the yield of sweet corn over the three year period was as follows:

Nitrogen t value 2.3*
Phosphorus t value-1.7
Potassium t value 2.3*
* Significant differences (5% level)

These values indicate that the beneficial influence of nitrogen and potassium on the yield of sweet corn is significant. At the same time phosphorus caused a depressing effect on the yield of sweet corn.

Beans

No significant difference due to treatments was observed from the 1947 yields of beans. The yields of all fertilizer treatments as indicated in Table 6 were lower than check.

Table 6. Bean Yields in Pounds per Plot for 1947

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	28.2	24.1	24.7	26.7
N	26.7	25.8	22.1	24.7
P	27.8	24.1	22.4	24.8
K	27.6	18.8	24.8	23.7
NP	22.5	17.4	26.6	22.2
PK	24.1	23.9	22.2	23.4
NK	27.6	26.6	23.8	26.0
nil	29.9	26.4	25.6	27.3
Mean	26.8	23.4	24.0	
F value (treatment)			1.26	

The 1948 bean results were somewhat similar to those obtained from sweet corn in 1948. Differences due to treatments were highly significant and as with sweet corn, phosphorus seemed to have a toxic effect when used alone but when combined with potassium produced the highest yields. Unlike the sweet corn results, however, nitrogen and potassium did not cause significant yield responses. The combination of nitrogen-phosphorus produced significantly lower yields, but when all three elements were combined favourable yield effects resulted. These yield data are presented in Table 7 as well as the minimum significant differences.

Table 7. Bean Yields in Pounds per Plot for 1948

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	32.2	32.5	27.0	30.6 *
N	26.0	22.6	28.0	25.5
P	19.5	20.0	12.5	18.3 *
K	28.2	22.6	26.8	25.8
NP	27.0	22.8	18.5	22.4 *
PK	34.5	31.0	27.2	30.9 *
NK	31.8	28.2	27.8	29.2
nil	30.0	26.0	25.8	27.2
Mean	28.6	25.7	24.2	

F value (treatment) 9.8**

Minimum significant differences for treatment is ±2.55 pounds

* Significant differences (5% level)

The early effect of some of the treatments on the pre-bloom bean plants is illustrated in Figures 8,9,10 and 11.

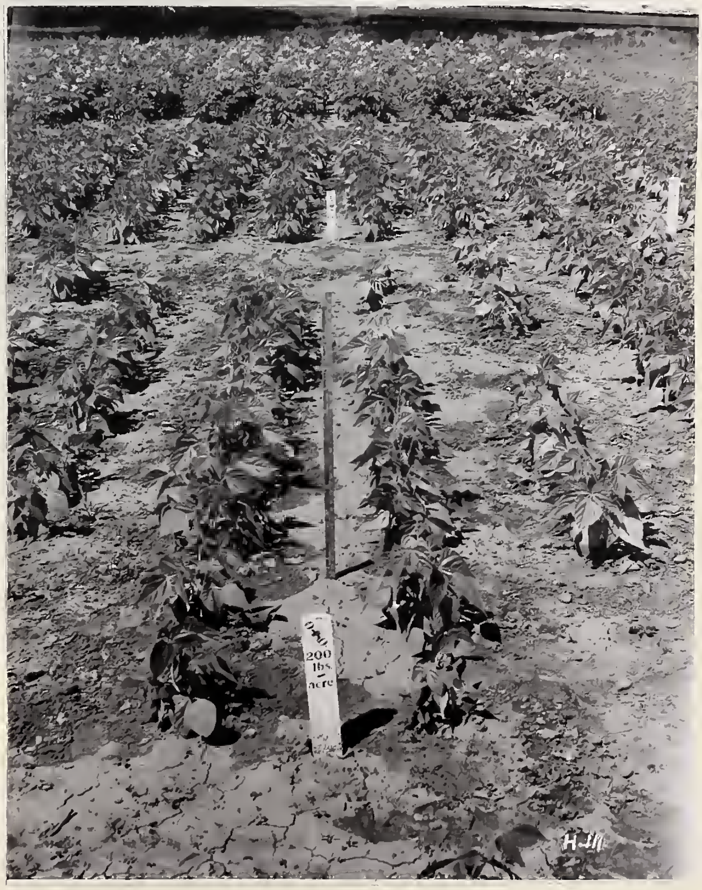

Fig.8. The effect of phosphorus on beans 1948

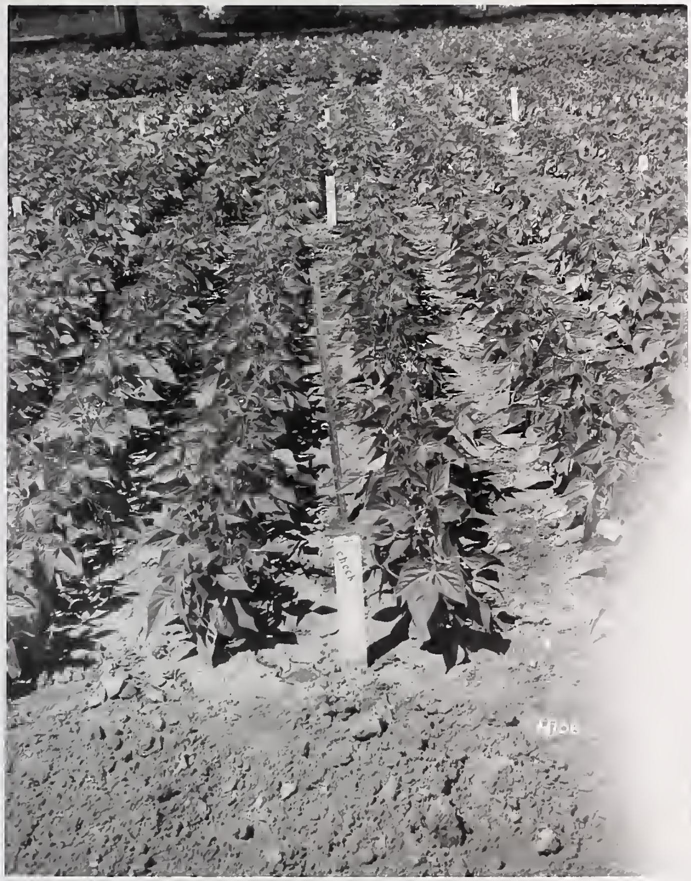

Fig. 9. The effect of no fertilizers on beans 1948

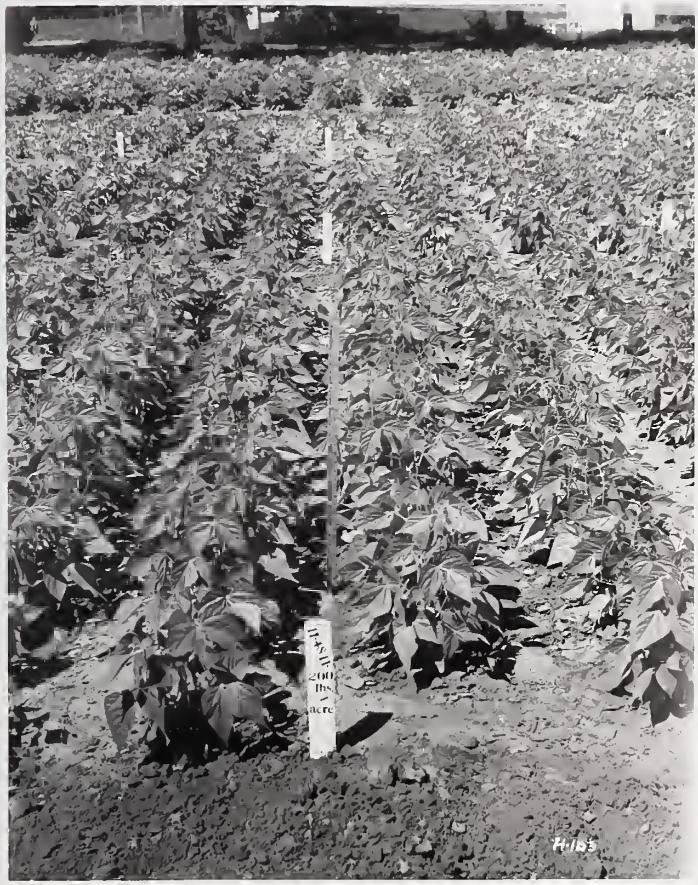

Fig. 10. The effect of the complete fertilizer on beans 1948

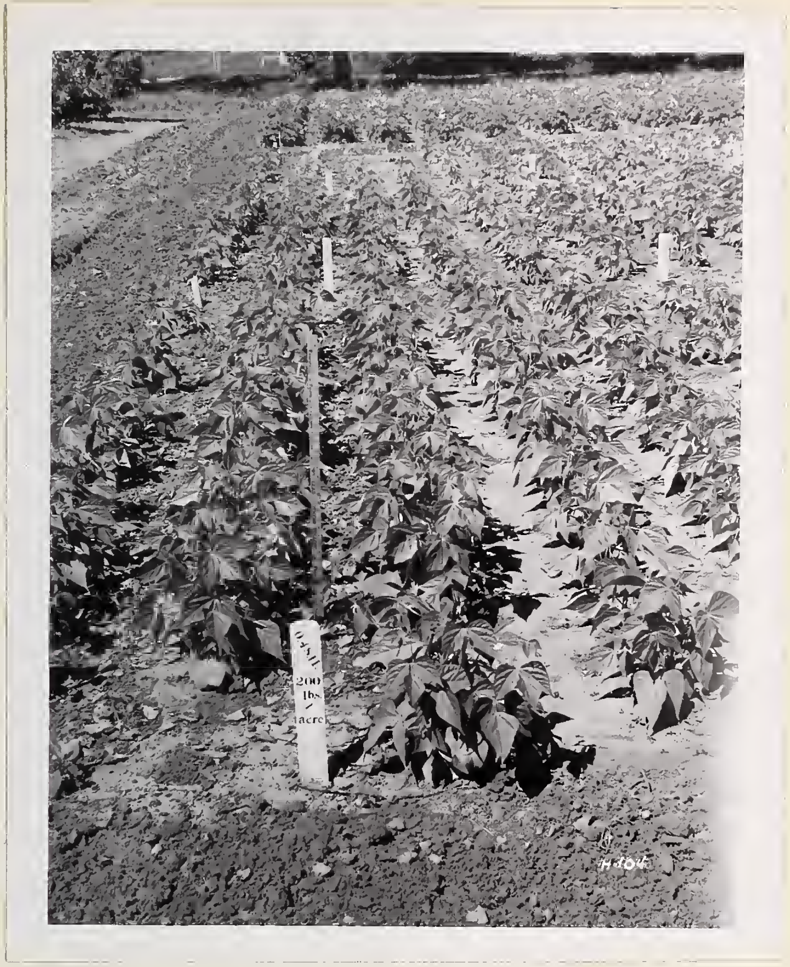

Fig. 11. The effect of phosphorus-potassium on beans 1948

The analysis of the 1949 yields of beans indicated no significant differences due to treatments. This was somewhat similar to the 1947 analysis. In 1949, however, just two fertilizer treatments, and not all seven, were lower in yield than check. The lowest yielding treatments were nitrogen-potassium and potassium. It is interesting to note that the highest yields were produced by phosphorus-

potassium in both 1948 and 1949. The two treatments producing the lowest yields in 1948 i.e. phosphorus and nitrogen-phosphorus resulted in good yields in 1949. The 1949 results are presented in Table 8.

Table 8. Bean Yields in Pounds per Plot for 1949

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	18.6	20.6	20.6	19.9
N	15.5	16.4	23.8	18.6
P	16.8	21.6	18.3	18.9
K	19.6	11.4	17.4	16.2
NP	17.2	21.8	19.0	19.4
PK	20.6	24.0	17.2	20.6
NK	9.5	17.0	20.0	15.5
nil	15.4	16.6	18.3	16.8
Mean	16.6	18.6	19.3	

F value (treatment) 0.9

The somewhat different treatment effects occurring in 1949 with beans are shown in Figures 12 and 13. As pointed out by Miller and Cook (18) the early responses caused by fertilizers are not always apparent in the final yield.

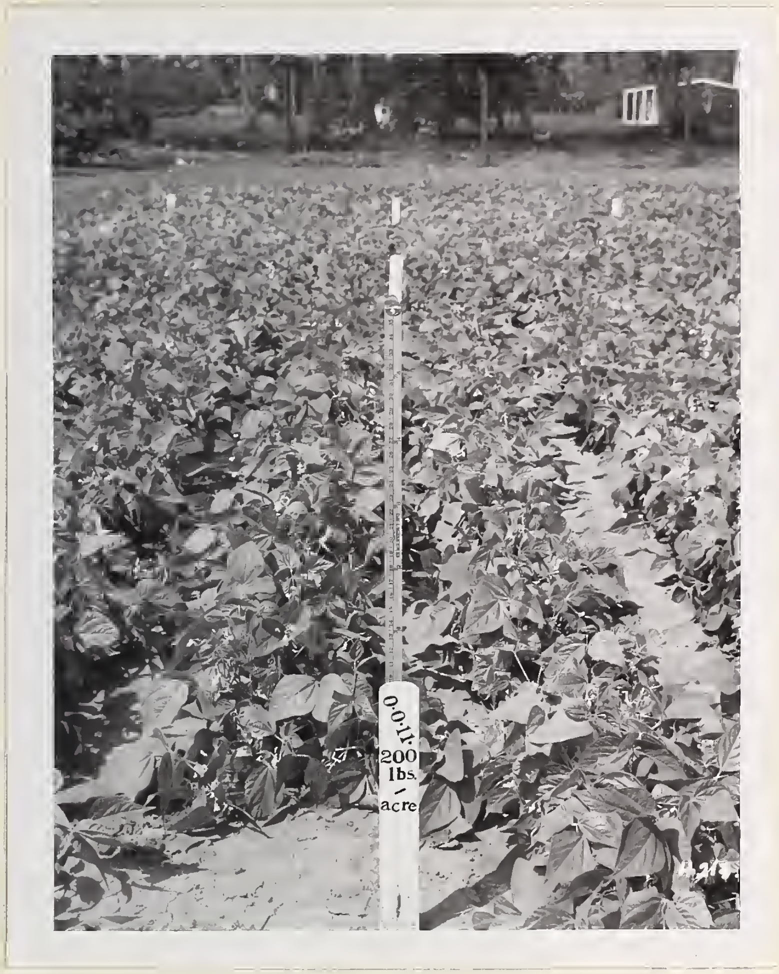

Fig. 12. Potassium shows good early effect on beans in 1949

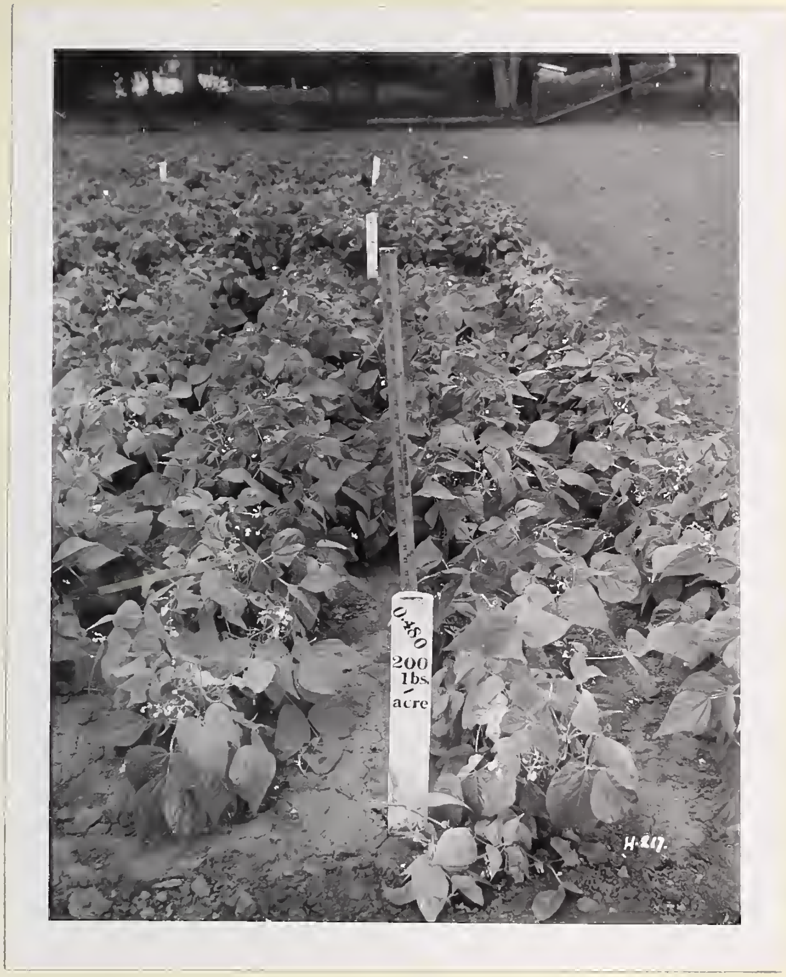

Fig. 13. Beans responded much better to phosphorus in 1949 than in 1948

Table 9. The Mean Yields of Beans in Pounds - 1947-49

Treatment	1947	1948	1949	Mean
NPK	26.7	30.6	19.9	25.7
N	24.7	25.5	18.6	22.9
P	24.8	18.3	18.9	20.6
K	23.7	25.8	16.2	21.9
NP	22.2	22.4	19.4	21.3
PK	23.4	30.9	20.6	25.0
NK	26.0	29.2	15.5	23.6
nil	27.3	27.2	16.8	23.8
Mean	24.7	26.2	18.2	

F value (treatment) 1.1

The influence of the individual elements on the yield of beans over the three year period was as follows:

Nitrogen t value	1.2
Phosphorus t value	0.05
Potassium t value	1.8

These values indicate apparent response to potassium and nitrogen. Phosphorus appeared to have a negligible effect on the yield of beans.

Lettuce

The late start of the lettuce experiment in 1947 made it impossible to use transplants and the lettuce had to be seeded directly into the plot rows. The plants on these seed rows were later thinned to 14 inches apart. Stands were not good especially in the first replicate possibly due to soil heterogeneity, uneven irrigating or both these factors. This may explain why within certain treatments, the replicates produced uneven yield records.

Significant differences due to treatments occurred in 1947 but would seem to have been caused by the discrepancies between replicates rather than to actual (treatment) effects. Nitrogen and nitrogen-potassium produced the weakest response. The only fertilizer treatments higher than check were the complete combination of nitrogen, phosphorus and potassium and phosphorus-potassium but they were not significantly higher. The data for 1947 are presented in Table 10.

Table 10. Lettuce yields in pounds of heads per plot for 1947

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	18.2	23.2	24.6	22.0
N	5.8	12.0	9.4	9.1 *
P	8.5	11.8	15.6	13.0 *
K	8.6	13.6	11.2	13.5
NP	3.9	30.8	18.2	17.6
PK	14.7	22.5	24.5	20.5
NK	14.4	7.8	14.4	12.2 *
nil	15.2	18.4	20.9	18.2
Mean	11.2	17.8	17.4	

F value (treatment) 3.2 *

The minimum significant difference for treatment is ± 4.8 pounds

*Significant difference (5% level)

The transplanting of lettuce in 1948 apparently did much to correct the lack of uniformity encountered in 1947. All fertilizer treatments produced significantly higher yields of lettuce than check. As in 1947 it was phosphorus-potassium that caused/one of the highest yields. The yield from this treatment was also significantly greater than both nitrogen and potassium. The 1948 data are presented in Table 11.

Table 11. Lettuce yields in pounds of heads per plot for 1948

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	31.5	38.0	30.5	33.3 *
N	33.0	33.0	30.8	32.2 *
P	34.0	35.5	31.5	33.7 *
K	27.1	35.0	32.0	31.4 *
NP	31.2	35.0	35.0	34.4 *
PK	34.5	37.2	35.0	35.6 *
NK	34.0	38.0	33.2	35.0 *
nil	27.0	31.3	25.5	27.9
Mean	31.5	35.4	31.7	

F value (treatment) 4.7 **

The minimum significant difference for the treatment is ± 2.4

*Significant difference (5% level)

The lettuce experiment in 1949 was beset with some difficulties. A physiological disorder within the plants, of unknown origin and non-pathological, caused much trouble. The lettuce plants, shortly before reaching maturity, would wither and die in a matter of a few days. Even more strange was the tendency of this disorder to be confined to the first replicate. Therefore it was decided to adjust the mean yields by co-variance analysis. The original yields and means as well as the corrected means are presented in Table 12, together with the minimum significant difference which was calculated for the adjusted data. Only two fertilizer treatments in 1949 produced yields significantly different from check, nitrogen-phosphorus being significantly higher and nitrogen significantly lower than check.

Table 12. Lettuce yields in pounds of heads per plot for 1949

Treatment	Rep.1	Rep.2	Rep.3	Mean	Corrected Mean
NPK	10.4	13.8	31.3	18.5	37.1
N	15.2	21.4	26.6	21.0	32.8 *
P	22.6	31.3	36.8	30.2	38.1
K	10.4	24.7	20.2	18.4	34.9
NP	23.0	37.8	31.8	30.8	38.7 *
PK	23.1	35.1	30.2	29.4	38.0
NK	10.8	26.0	33.2	23.3	35.4
nil	15.6	31.2	39.0	28.6	36.6
Mean	16.4	26.4	31.1		

F value (treatment) 4.4 *

The minimum significant difference for treatments is ± 2.0 pounds

* Significant difference (5% level)

The averaged yields of lettuce for 1947-49 indicated that treatments were significantly different. One fertilizer treatment, phosphorus-potassium, caused significantly higher lettuce yields than check. Nitrogen and potassium yields were significantly lower than check. Data for the three years are presented in Table 13.

Table 13. The Mean Yields of Lettuce in Pounds - 1947-49

Treatment	1947	1948	1949	Mean
NPK	22.0	33.3	18.5	24.6
N	9.1	32.2	21.0	20.8 *
P	13.0	33.5	30.2	25.6
K	13.5	31.4	18.4	21.0 *
NP	17.6	34.4	30.2	27.6
PK	20.5	35.6	29.4	28.5 *
NK	12.2	35.0	23.3	23.5
nil	18.2	27.9	28.6	24.9
Mean	15.8	32.9	23.0	

F value (treatment) 2.24 *

The minimum significant difference for treatment is ± 3.6 pounds

* Significant difference (5% level)

To check the field lettuce yields a series of pot cultures was carried out in the greenhouse during the winter of 1949-50. For this trial treatments were made in triplicate and soil from the original experimental area was used. The results are presented in Table 14. As with the field results the greatest yield response was due to phosphorus-potassium.

Table 14. Mean Pot Culture Yields with Lettuce (grams)

NPK	22.0
N	24.6
P	24.3
K	20.4
NP	27.5
PK	28.2
NK	24.4
nil	9.2

In the pot culture trials, all fertilizer applications produced marked increases in yield, and the untreated pots made uniformly meagre growth.

The influence of the individual elements on the yield of field grown lettuce over the three year period was as follows:

Nitrogen t value	0.3	
Phosphorus t value	3.6	**
Potassium t value	-0.4	

** Highly significant difference (1% level)

These values attribute a highly significant increase in lettuce yields to phosphorus, a negligible yield effect to nitrogen and a somewhat depressed effect due to potassium.

Carrots

The 1947 experiment with carrots produced no significant differences in yield due to treatments. The yields of the replicates were quite uniform with the exception of nitrogen-potassium and check. All fertilizer treatments, with the exception of phosphorus-potassium, were higher in yield than check, although not significantly so. Phosphorus and potassium produced the greatest yield effect. The 1947 yields are presented in Table 15.

Table 15. Carrot yields in pounds per plot for 1947

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	62.0	73.0	70.0	68.3
N	71.0	68.0	63.0	67.3
P	77.0	78.0	63.0	72.7
K	68.0	76.0	73.0	72.3
NP	77.0	70.0	69.0	72.0
PK	59.0	64.0	63.0	63.0
NK	58.0	74.0	67.0	66.3
nil	74.0	63.0	59.0	65.3
Mean	68.2	70.8	65.8	

F value (treatment) 1.26

The results obtained in 1948 were not unlike those of 1947 in that yield differences did occur but not significantly different. Three treatments yields were lower than check, phosphorus, nitrogen and phosphorus-potassium. Of these, phosphorus-potassium caused the poorest response by carrots. This treatment was associated with the greatest yield increase in 1947. Nitrogen-potassium and nitrogen-phosphorus were the two treatments causing the highest yields in 1948. The 1948 data are presented in Table 16.

Table 16. Carrot yields in pounds per plot for 1948

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	60.5	68.6	63.2	64.0
N	56.9	43.7	56.9	52.5
P	33.0	59.5	60.0	50.8
K	61.1	51.7	59.9	57.6
NP	72.3	69.0	59.6	67.0
PK	56.7	50.4	44.4	50.5
NK	57.8	74.1	81.5	71.1
nil	57.4	63.2	38.8	53.1
Mean	57.0	60.0	58.0	

F value (treatment) 1.9

As in the two previous years the 1949 yields of carrots produced no significant difference due to treatments. Unlike the results of the two previous years, all fertilizer treatments caused higher yields than check. As indicated in Table 17, phosphorus-potassium produced the greatest response in yield followed by potassium.

Table 17. Carrot yields in pounds per plot for 1949

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	35.5	45.6	41.9	41.0
N	37.8	41.1	51.8	43.6
P	44.8	39.0	43.4	42.4
K	50.6	44.6	44.9	46.7
NP	43.8	38.9	42.1	41.6
PK	37.6	50.6	54.4	47.5
NK	43.5	48.9	43.7	45.4
nil	33.6	46.1	35.5	38.4
Mean	40.9	44.4	44.7	

F value (treatment) 1.0

The more uniform roots produced by the fertilizer treatments as compared with check is apparent in Figures 14,15 and 16.

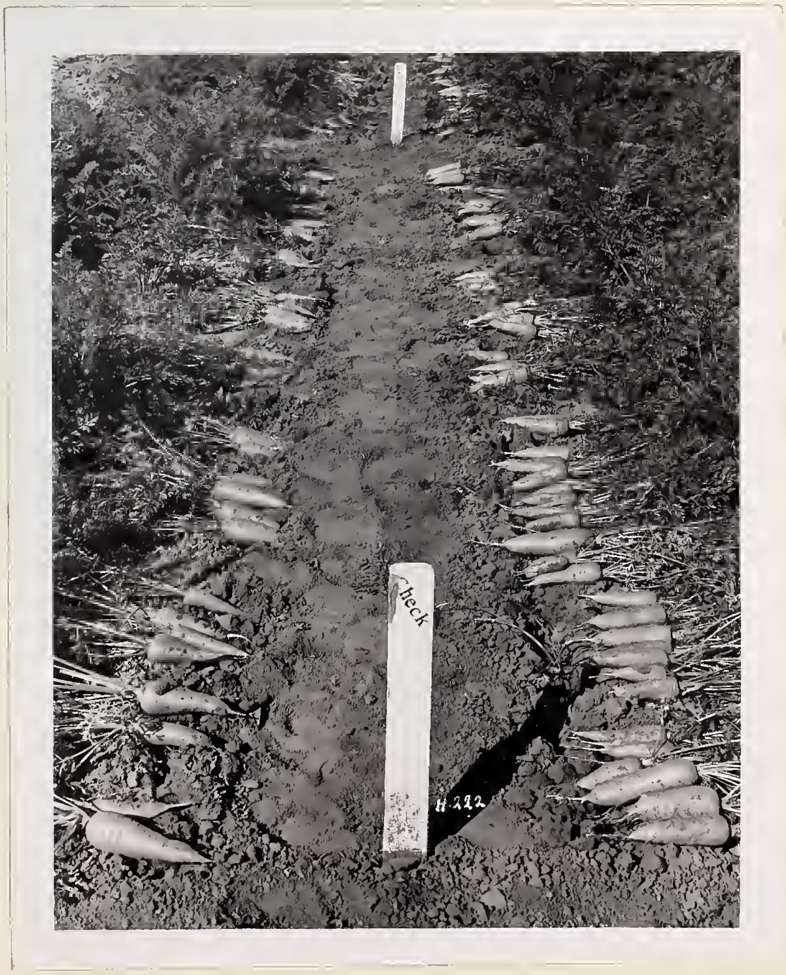

Fig. 14. The effect of no fertilizer on carrots 1949

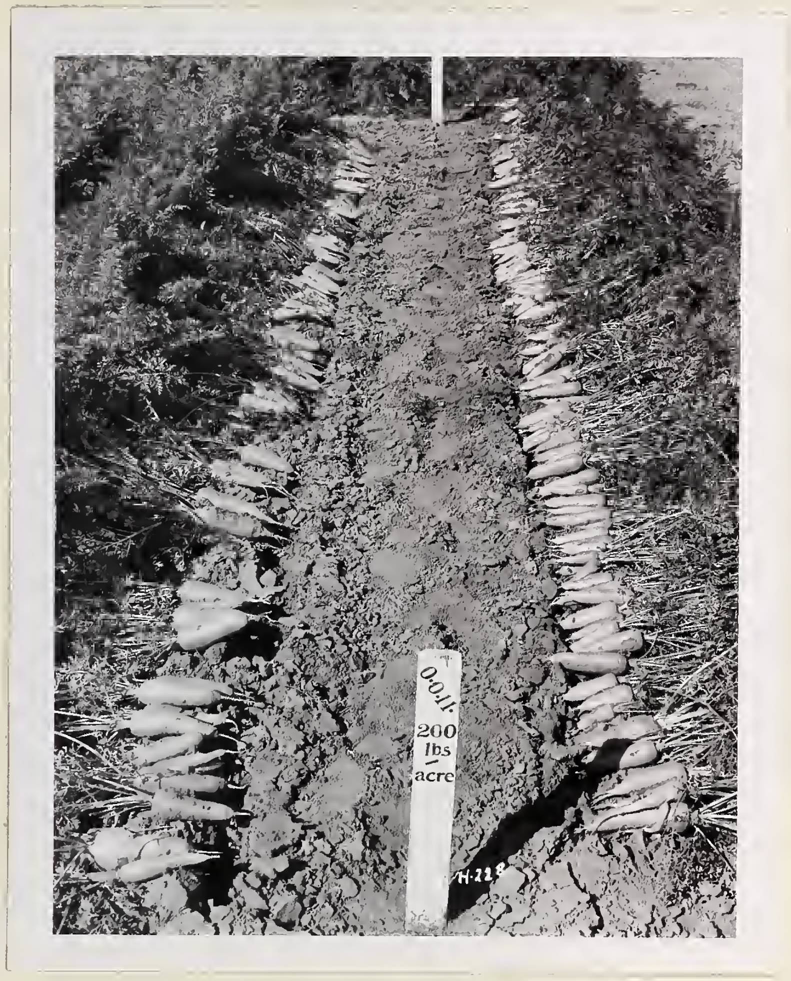

Fig. 15. The effect of potassium on carrots 1949

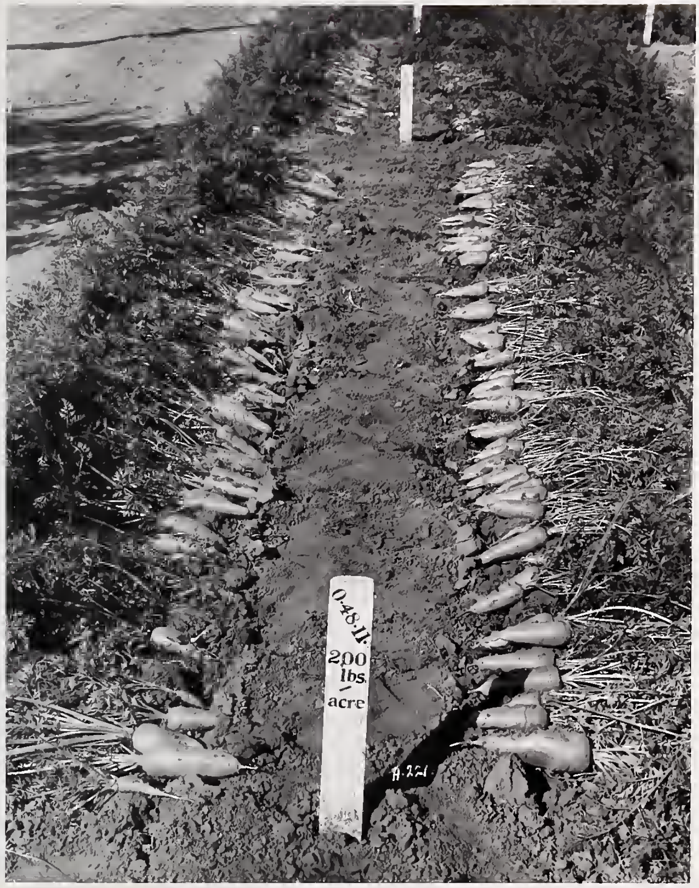

Fig. 16. The effect of phosphorus-potassium on carrots 1949

The mean yields for 1947-49 indicated no significant differences due to treatments. None of the fertilizer treatments, however, was associated with lower yields than check. Nitrogen-potassium and nitrogen-phosphorus resulted in the greatest response by carrots. Potassium produced the best yields on the basis of individual elements.

The three year mean yields are presented in Table 18.

Table 18. The Mean Yields of Carrots in Pounds - 1947-49

Treatment	1947	1948	1949	Mean
NPK	68.3	64.0	41.0	57.8
N	67.3	52.5	43.6	54.5
P	72.7	50.8	42.4	55.3
K	72.3	57.6	46.7	58.8
NP	72.0	67.0	41.6	60.2
PK	63.0	50.5	47.5	53.6
NK	66.3	71.1	45.4	60.9
nil	65.3	53.1	58.4	52.3
Mean	68.3	58.3	43.3	

F value (treatment) 1.6

The influence of the individual elements on the yield of carrots over the three year period was as follows:

Nitrogen t value	2.2 *
Phosphorus t value	0.1
Potassium t value	1.1

* Significant difference (5% level)

These values indicate (a) that nitrogen significantly increases carrot yields, (b) that potassium applications have an unestablished trend toward yield increases, and (c) that phosphorus has no effect whatsoever.

To provide a check on the field carrot yields, a series of pot cultures was grown in the greenhouse during the winter of 1949-50. As with the lettuce pot cultures the treatments were in triplicate and soil from the original experimental area was used. The results are presented in Table 19. The yield trends were nearly the same as the field

results. Nitrogen-phosphorus was responsible for the greatest pot culture yield increases, and nitrogen-potassium the second highest. In the field the positions of these two fertilizers were reversed.

Table 19. Mean Pot Culture Yields of Carrots and Three-Year Field Yields

Treatment	Pot Culture Mean Yields (gm.)	Three-Year Mean Field Yields (lb.)
NPK	9.8	57.8
N	5.3	54.5
P	10.2	55.3
K	10.3	58.8
NP	18.3	60.2
PK	12.0	53.6
NK	13.3	60.9
nil	2.7	52.3

Cabbage

The 1947 experiment with cabbage was characterized by considerable lack of uniformity between replicates. No significant differences due to treatments occurred as one might expect with this leafy crop. Nitrogen did produce the greatest yield increases and potassium (0-0-11) the lowest. In all, four of the fertilizer treatments resulted in lower yields than check. The data are presented in Table 20.

Table 20. Cabbage yields in pounds of heads per plot for 1947

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	75.0	45.0	66.0	62.0
N	60.0	76.0	92.0	76.0
P	69.0	65.3	68.3	67.5
K	40.0	72.0	58.6	56.5
NP	61.0	51.3	61.3	57.9
PK	57.0	74.0	79.0	70.0
NK	59.0	57.0	62.0	59.3
nil	68.0	43.3	75.0	62.1
Mean	61.1	60.5	70.3	

F value (treatment) 1.0

The 1948 experiment produced results similar to those of 1947. No significant difference due to treatments occurred. However, instead of three fertilizer treatments producing higher yields than check there were five. As in 1947 nitrogen was responsible for the greatest increase in yield. Phosphorus and potassium caused lower yields than check. The complete fertilizer, nitrogen-phosphorus-potassium resulted in an intermediate yield response. Again there was evidence that the plot soil lacked uniformity. The 1948 results are presented in Table 21.

Table 21. Cabbage yields in pounds of heads per plot for 1948

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	51.0	64.2	67.0	60.8
N	57.5	62.2	75.5	65.0
P	53.0	36.0	51.0	46.6
K	42.5	51.0	43.5	45.6
NP	51.0	57.0	57.0	55.3
PK	60.5	60.8	55.5	58.9
NK	47.5	44.5	79.0	57.0
nil	54.0	38.5	62.5	51.6
Mean	52.1	51.8	61.4	

F value (treatment) 1.7

The 1949 cabbage yields followed the pattern set in 1947 and 1948 in which no significant differences due to treatments occurred and nitrogen resulted in the greatest increase in yield. As in 1948, the complete fertilizer nitrogen-phosphorus-potassium produced the next highest yield increases. Nitrogen-phosphorus and nitrogen-potassium were responsible for the lowest yields. The lack of uniformity between replicates was more noticeable than in previous experiments. The 1949 experimental results with cabbage are presented in Table 22.

Table 22. Cabbage yields in pounds of heads per plot for 1949

Treatment	Rep.1	Rep.2	Rep.3	Mean
NPK	38.7	38.0	45.8	40.6
N	50.3	23.5	51.8	41.5
P	45.1	23.8	45.3	38.0
K	25.8	16.5	52.2	31.5
NP	28.5	23.5	40.8	30.9
PK	24.6	38.3	43.2	35.1
NK	36.2	21.5	36.0	31.2
nil	51.5	25.5	38.8	38.6
Mean	37.6	26.6	44.2	

F value (treatment) 0.8

The mean cabbage yields for 1947-49 indicated no significant difference due to treatments. Four of the fertilizer treatments were lower in yields than check. Nitrogen application was responsible for the greatest yield increase, and that of potassium was associated with the lowest yields but when the latter was combined with phosphorus a much better response in yield was obtained.

Cabbage seemed to deplete the soil more than any of the other vegetable crops in this experiment. An examination of the yearly means in Table 23 will bear this out. The appearance of the cabbage plants in 1949 also indicated possible hunger signs. The discrepancies between replicates may be further explained by the possible existence of pockets of varying fertility in the plot area. The yearly mean yields were as follows:

1947 - 63.9 pounds
1948 - 55.1 pounds
1949 - 35.9 pounds

The three-year mean yields are presented in Table 23.

Table 23. The Mean Yields of Cabbage in Pounds - 1947-49

Treatment	1947	1948	1949	Mean
NPK	62.0	60.8	40.6	54.5
N	76.0	65.0	41.5	60.8
P	67.5	46.6	38.0	50.7
K	56.5	45.6	31.5	44.5
NP	57.9	55.3	30.9	48.0
PK	70.0	58.9	35.1	54.6
NK	59.3	57.0	31.2	49.2
nil	62.1	51.6	38.6	50.8
Mean	63.9	55.1	35.9	

F value (treatment) 1.8

The influence of the individual elements on the yield of cabbage over the three-year period was as follows:

Nitrogen t value	1.7
Phosphorus t value	0.3
Potassium t value	-1.04

Although no significant differences could be established, there was a strong indication that the use of nitrogenous fertilizers favoured increased cabbage yields. The response due to phosphatic compounds was negligible, whereas application of potassium depressed yields somewhat.

II. Effect of Various Combinations of Fertilizers on Vegetable Maturity

It was deemed undesirable, chiefly because of the variable nature of the data, to attempt statistical analysis to determine the influence of the three major elements on maturity.

Sweet Corn

A comparison of two years' data was made to determine the effect of fertilizer treatments on sweet corn maturity. Mean number and weight of ears for each treatment at the first and last harvest formed the basis for these particular observations. The data for 1948 and 1949 are presented in Table 24. It is evident that not all fertilizer treatments hastened maturity. At the first harvest the complete fertilizer, nitrogen-phosphorus-potassium, produced the greatest number and weight of mature ears and phosphorus-potassium produced the heaviest individual ears. At the last harvest, potassium was responsible for the production of the greatest number of ears and phosphorus-potassium was responsible for the fewest ears, thus indicating the value of this latter fertilizer combination in promoting earlier maturing ears.

Table 24. Two Years' Yield Data on Effect on Maturity of the Treatments

First Harvest
Treatment

	NPK	N	P	K	NP	PK	NK	Nil
Mean Number of Ears	17.5	15.3	12.3	11.9	15.7	14.5	13.8	11.7
Mean Weight (pounds)	12.1	10.4	7.4	9.2	10.5	10.3	9.1	7.7
Single Ear Weight	0.69	0.64	0.67	0.66	0.68	0.82	0.63	0.66

Last Harvest
Treatment

	NPK	N	P	K	NP	PK	NK	Nil
Mean Number of Ears	19.7	16.9	13.5	21.0	20.2	14.4	11.5	17.4
Mean Weight (pounds)	9.0	8.5	6.6	13.3	7.5	7.0	5.7	7.6
Single Ear Weight	0.46	0.50	0.48	0.63	0.37	0.49	0.49	0.43

The general effects caused by the individual elements on maturity of sweet corn were noted from three years' mean weights at first and last harvests. The data from which these observations were made are presented in Table 25. Phosphorus certainly seemed to promote maturity of sweet corn the most, then nitrogen. Potassium behaved as the other two treatments at the first harvest but delayed maturity somewhat at the last harvest.

Table 25. The Three Year Effect of N, P, and K on Maturity of Sweet Corn

(mean pounds per treatment)

	First Harvest		Last Harvest	
Effect of Nitrogen	N	No N	N	No N
NPK vs. PK	10.3	10.7	7.2	5.8
NP vs. P	10.2	7.3	6.4	5.7
NK vs. K	8.1	8.9	5.4	10.4
N vs. Nil	9.6	9.0	6.4	6.5
Total	38.2	35.9	25.4	28.4
Effect of Phosphorus	P	No P	P	No P
NPK vs. NK	10.3	8.1	7.2	5.4
NP vs. N	10.2	9.6	6.4	6.4
PK vs. K	10.7	8.9	5.8	10.4
P vs. Nil	7.3	9.0	5.7	6.5
Total	38.5	35.6	25.1	28.7
Effect of Potash	K	No K	K	No K
NPK vs. NK	10.3	10.2	7.2	6.4
NP vs. N	10.7	7.3	5.8	5.7
PK vs. K	8.1	9.6	5.4	6.4
P vs. Nil	8.9	9.0	10.4	6.5
Total	38.0	36.1	28.8	25.0

Beans

The effect of the individual elements on the maturity of beans could be studied using two years' mean weights at first and last harvests. These data are presented in Table 26. Unlike sweet corn only potassium hastened the maturity of beans. As indicated by the data in Table 26 nitrogen and phosphorus promoted early maturity at the first harvest but they also had a tendency to retard maturity at the last harvest.

Table 26, The Two Year Effect of N, P, and K on Maturity of Beans

(mean pounds per treatment) ¢

	First Harvest		Last Harvest	
Effect of Nitrogen	N	No N	N	No N
NPK vs. PK	8.6	9.7	5.2	5.0
NP vs. P	5.9	4.8	6.0	5.6
NK vs. K	7.6	7.5	4.5	4.2
N vs. Nil	7.1	6.2	4.8	4.0
Total	29.2	28.2	20.5	18.8
Effect of Phosphorus	P	No P	P	No P
NPK vs. NK	8.6	7.6	5.2	4.5
NP vs. N	5.9	7.1	6.0	4.8
PK vs. K	9.7	7.5	5.0	4.2
P vs. Nil	4.8	6.2	5.6	4.0
Total	29.0	28.4	21.8	17.5
Effect of Potassium	K	No K	K	No K
NPK vs. NP	8.6	5.9	5.2	6.0
PK vs. P	9.7	4.8	5.0	5.6
NK vs. K	7.6	7.1	4.5	4.8
K vs. Nil	7.5	6.2	4.2	4.0
Total	33.4	24.0	18.9	20.4

¢ 1948 and 1949

Lettuce

A three year study of the effect of each treatment on maturity of lettuce was based on a comparison of mean number and weight of heads at the first and last harvest.

The majority of the fertilizer treatments at the first harvest promoted early maturity, that is all treatments but potassium and phosphorus-potassium. These results are set out in

Table 27. At the last harvest only nitrogen-phosphorus seemed to retard maturity.

Table 27. Three Year Yield Data of the Effect of Treatment on Maturity

First Harvest
Treatment

	NPK	N	P	K	NP	PK	NK	Nil
Mean Number of Heads	7.3	7.4	7.4	5.5	8.2	5.7	7.0	5.9
Mean Weight (pounds)	8.3	8.6	9.1	8.3	9.8	10.1	8.2	9.1
Single Head Weight	1.14	1.16	1.23	1.51	1.20	1.77	1.17	1.54

Last Harvest
Treatment

	NPK	N	P	K	NP	PK	NK	Nil
Mean Number of Heads	4.3	3.8	2.9	1.9	5.6	4.6	2.9	4.6
Mean Weight (pounds)	3.5	4.6	4.3	3.4	5.2	5.7	4.3	5.8
Single Head Weight	0.81	1.21	1.48	1.79	0.92	1.24	1.48	1.26

The effect of the individual elements on maturity of lettuce was based on three year mean weights at first and last harvests. These results are presented in Table 28. Phosphorus promoted early maturing heads. Nitrogen and potassium had a slight tendency to slow down maturity.

Table 28. The Three Year Effect of N, P, and K on Maturity of Lettuce

(mean pounds per treatment)

	First Harvest		Last Harvest	
Effect of Nitrogen	N	No N	N	No N
NPK vs. PK	8.3	10.1	3.5	5.7
NP vs. P	9.8	9.1	5.2	4.3
NK vs. K	8.2	8.3	4.3	3.4
N vs. Nil	8.6	9.1	4.6	5.8
Total	34.9	36.6	17.6	19.2
Effect of Phosphorus	P	No P	P	No P
NPK vs. NK	8.3	8.2	3.5	4.3
NP vs. N	9.8	8.6	5.2	4.6
PK vs. K	10.1	8.3	5.7	3.4
P vs. Nil	9.1	9.1	4.3	5.8
Total	37.3	34.2	18.7	18.1
Effect of Potassium	K	No K	K	No K
NPK vs. NP	8.3	9.8	3.5	5.2
PK vs. P	10.1	9.1	5.7	4.3
NK vs. N	8.2	8.6	4.3	4.6
K vs. Nil	8.3	9.1	3.4	5.8
Total	34.9	36.6	16.9	19.9

Carrots and Cabbage

It was not possible to report on the effects of either treatments or individual elements on the maturity of these two crops as all treatments were harvested at the same time and little difference in maturity could be observed.

DISCUSSION OF RESULTS

The three major elements affected the yield of sweet corn. The differences that were caused by the fertilizer treatments were however not conclusive. These differences could be attributed partly to soil heterogeneity but some yield differences did occur. Nitrogen and potassium resulted in much greater yields than check and when these two elements were combined they encouraged the highest yields. A further indication of the beneficial effects of these two elements occurred when they were combined with phosphorus, which when alone produced the lowest yields, but when combined with these two treatments produced considerably higher yields. These rather definite trends might even have been significant if a portion of the fertilizer had not been placed in contact with the seed. At least one experiment cited in the literature review presented evidence to show that placement of fertilizers in contact with corn seed reduced germination and root development (29). The significant differences due to the effect of the individual elements point also to the beneficial influence of the fertilizer treatments; e.g. nitrogen and potassium caused significant influences on the yields of sweet corn, whereas phosphorus appeared to depress yields.

An examination of the effects of the treatments on sweet corn occurring within years also indicates certain trends. Although there was no significant difference due to treatments during the first year of the experiment it was apparent that phosphorus was a necessary element. Other workers (15) have

found similar effects. Subsequent results however suggest that phosphorus retarded growth by sweet corn plants. Huelsen and Gillis (15) working with sweet corn in a phosphorus deficient soil found that increasing the amounts of phosphorus above a single dosage reduced yields. The additional application of phosphorus in 1948 together with the residue from 1947 could possibly have built up the concentration of phosphorus to the point where it became toxic to the plants, or else the large quantities of potassium utilized in 1948 could possibly have caused too great an uptake of phosphorus and thus bring about the toxic condition. As pointed out by De Turk (7), Bushnell (2) and Huelsen and Gillis (15) the addition of nitrogen or potassium or both resulted in a much greater uptake of phosphorus.

There seems to be little doubt that the spring weather conditions of 1948 increased the potassium uptake of certain crops. De Turk (7) stated that sweet corn makes high demands on soil potassium. In this experiment the pressure of large quantities of phosphorus may have created a further demand for additional potassium and nitrogen. Although the soil of the experimental area was initially well supplied with available potassium, one would suppose that constant cropping and irrigation would lead sooner or later to the necessity of adding this element to the sweet corn fertilizer program.

Early maturing crops are of primary importance to the commercial producer in this area because of the short growing sea-

son. Phosphorus seemed to promote the formation of early ears more readily than either nitrogen or potassium. Potassium resulted in the latest maturing ears and phosphorus-potassium fertilizer produced the heaviest individual ears.

The effect on beans of most of the fertilizer treatments during the three year period resulted in few yields being higher than the check yield. It was observed however that all three of the major elements when combined produced a greater effect than when applied singly. Potassium appeared to be the most important element for beans as is indicated by the increased yields of phosphorus-potassium over phosphorus alone and nitrogen-phosphorus. This is further substantiated by the greater effect of potassium on beans as an individual element than either nitrogen or phosphorus over the three years. These results are not in agreement with those of other workers. Ware (35) found that the effect of potash was the least and the effect of phosphorus the greatest, insofar as snap bean yields are concerned.

It is felt that the poor yields both in 1947 and 1949 together with the rather inconsistant results of 1948 can be attributed partly to the placement of a portion of the fertilizer with the seed. Several workers (5, 26, 33) have shown that under their conditions reduced yields occurred when fertilizer was placed in contact with bean or pea seeds. Apparently the placing of part of the fertilizer with the seed in this experiment had an inhibiting effect for as is indicated by the three year mean

yields ohly two treatments, the complete fertilizer and phosphorus-potassium, produced greater yields than check. Yet Thompson (33) and Shoemaker (29) indicate that beans respond well to fertilizers especially nitrogen and potassium.

Miller et al (18) found that beans are very seriously affected by adverse weather conditions during flowering and setting of pods and often the fertilizer effect is nullified. They explained this as being due to moisture conditions and water requirements. As presented in the literature review these workers suggest that when the soil moisture content is low during the blooming period the greater vegetative growth in the fertilized plots causes a greater demand for water by the leaves and there is not sufficient for a maximum set of pods. On the unfertilized plot on the other hand, a smaller demand for water by the leaves of the smaller plants might allow a greater set of pods. These conditions could have existed during the three years of this experiment especially since irrigation was the only means of supplying moisture to the plants.

Potassium produced the earliest maturing beans. This was not strange in the light of other results. Cooper (5) states that potassium generally is considered to be intermediate between too much phosphorus or nitrogen in its effect on the maturity of a particular crop. It is also possible that factors other than the elements may have influenced maturity as it apparently occurred in this experiment.

Lettuce was the only vegetable crop that responded significantly to individual treatments. Phosphorus seemed to be the important element in lettuce production as it produced greater yields than either nitrogen or potassium. Actually the latter two treatments were significantly lower than check. The effectiveness of phosphorus in increasing lettuce yields is particularly noticeable when it was combined with either nitrogen or potassium greatly increased yields occurred. It was phosphorus-potassium that produced the only yields significantly higher than check. The pot culture experiments further emphasize the important place of phosphorus in that like the three year mean field results it was phosphorus-potassium that produced the highest yields. The two sets of mean yields are presented in Table 29.

Table 29. Three Years' Mean Field Yields of Lettuce Compared with Mean Pot Culture Yields

Treatment	Three-Year Mean Field Yields	Pot Culture Mean Yields
	(lb.)	(gm.)
NPK	24.6	22.0
N	20.8 ✡	24.6
P	25.6	24.3
K	21.0 ✡	20.4
NP	27.6	27.5
PK	28.5 ✡	28.2
NK	23.5	24.4
Nil	24.9	9.2

✡ Significant difference (5% level)

The analogy of these two sets of data is interesting and indicates fairly conclusively the influence of phosphorus in

the production of lettuce. A similar association between field and greenhouse responses with carrots is shown in Table 19.

Many workers (4, 13, 17, 33, 37) agree that lettuce responds most favourably to phosphorus and several suggest that ammonium phosphate is a well balanced lettuce fertilizer. However this last statement does not agree entirely with the results of this experiment, where it was phosphorus-potassium that seemed to be the most balanced fertilizer for lettuce.

The lettuce results seem to illustrate most clearly the inter-relationship of the three major elements when used as vegetable fertilizers. It was pointed out earlier that phosphorus resulted in the highest lettuce yields whereas nitrogen and potassium produced significantly lower yields, but when combined, phosphorus with nitrogen and potassium with phosphorus greatly increased yields occurred. Yet the combination of all three elements produced a lower yield than either the phosphorus-potassium or nitrogen-phosphorus treatments. In other words, these results indicate that only specific fertilizer combinations are beneficial to lettuce, one of the three elements had an inhibiting effect on the others. Many workers report that for the full use of the three major fertilizing elements, they must be carefully balanced to meet the requirements of the crop (3, 27, 33).

An interpretation of the carrot results would lead one to conclude that under the conditions of this experiment fertilizer

was not required for maximum production. In the literature (33) it was found that carrots are heavy feeders and respond to fertilizers high in phosphorus. The results of this experiment indicated a response to nitrogen and not phosphorus. When combined with either potassium or phosphorus, nitrogen produced much higher yields than where no fertilizer was used. There is also some indication that potassium acted favourably on yield under the conditions of the trial reported herein. These trends are substantiated by the influence of the individual elements on carrots.

The cabbage yields seemed to indicate that fertilizers were unnecessary for this crop. Two factors however tend to contradict this observation. The first is the consistently higher yields caused by nitrogen and the second is that the close planting of the plots created a starvation condition. The mean yearly results presented in Table 23 show that despite the annual fertilizer applications, a decline in yields occurred with each subsequent year.

Many workers with cabbage (1, 8, 9, 19, 29) record similar responses to nitrogen. Fite (8) found that under alkaline soil conditions, ammonium sulphate produced the highest yields and that phosphoric acid (P_2O_5) and potassium had little effect on the yield of cabbage.

A summary of the general effects of the three major elements on these five vegetable crops in Southern Alberta is presented in Table 30. In a general way nitrogen had the great-

est beneficial influence on all vegetable yields. It should be noted that although phosphorus was the element considered lacking at the outset of the experiment, it produced the least response in these vegetable crops, lettuce yields excepted.

Table 30. Three Years' Effect of the Individual Elements on the Yield of Certain Vegetable Crops (t-tests)

Crop	Nitrogen	Phosphorus	Potassium
Sweet Corn	2.3 *	-1.7	2.3 *
Beans	1.2	-0.05	1.8
Lettuce	-0.3	3.6 **	-0.4
Carrots	2.2 *	0.01	1.1
Cabbage	1.7	0.3	-1.04
Means	1.4	0.5	0.8

* Significant difference (5% level)
** Significant difference (1% level)

CONCLUSIONS

This experiment indicates that a single fertilizer formulation will not meet the nutrient requirements of all vegetable crops under similar soil and climatic conditions. Most vegetable crops have certain specific requirements which the results reported herein do suggest;e.g. lettuce responded significantly to the same amounts of phosphorus that seemed to depress the yields of sweet corn and beans. Therefore to establish the trends of responses by the crops used in this study further work will be necessary on the basis of careful analyses of the soil of each plot so that the application of the three major elements can be adjusted to meet the needs of the crop concerned. Such procedure would not only accurately supply the nutrients required but would prevent the use of areas that could not possibly respond to treatments because the nutrient levels are already sufficiently high.

The value of applying part of the fertilizer with the seed in this experiment was not established. Rather it is concluded that this complicating factor was to some extent responsible for many of the conflicting results that occurred, particularly with sweet corn and bean yields. These two crops are considered sensitive to seed contact placement of fertilizers (29, 31, 33, 5). This points rather convincingly to the hazards of imposing additional factors upon an already thorough study without taking the necessary steps to provide adequate means of control. It should provide a useful guide for future work so that necessary checks will be ensured for all factors involved in each experiment.

SUMMARY

1. An experiment was conducted during the three year period 1947-49 under typical soil and climatic conditions of the irrigated areas of Southern Alberta to study the effect of nitrogen, phosphorus, and potassium on sweet corn, beans, lettuce, carrots, and cabbage.
2. Combinations of nitrogen, phosphorus, and potassium were used in an approximate 1-4-1 ratio based upon the readily available ammonium phosphate (11-48-0) fertilizer applied at 200 pounds per acre.
3. A simple randomized, three replicated experimental design was used.
4. The combined effect of the three major elements produced significant differences in yields of only one vegetable crop - lettuce. Yields of this crop showed highly significant increases due to phosphorus, and a slightly depressed effect on yield due to potassium and nitrogen.
5. In the case of the other four vegetables certain trends were indicated:
    a) Sweet corn and carrots showed definite responses to nitrogen. Bean and cabbage yields were increased slightly when nitrogen was added.
    b) Only negligible increases in carrot and cabbage yields were caused by phosphorus whereas sweet corn and bean yields were somewhat depressed.

c) Sweet corn, carrots, and bean yields were generally increased by potassium, whereas cabbage showed reduced yields.

6. Pot culture studies under greenhouse conditions with lettuce and carrots showed a close association with results obtained on the soil in the field.

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APPENDIX

Part I

1948 Sweet Corn Analysis

Treatment	Rep. 1	Rep. 2	Rep. 3	Sum	Mean
11-48-11	28.8	26.5	31.0	86.3	28.8
11-0-0	30.0	29.2	31.0	90.2	30.0 **
0-48-0	22.5	20.5	18.8	61.8	20.6 **
0-0-11	28.0	31.2	36.5	95.7	31.9 **
11-48-0	27.5	27.5	29.0	84.0	28.0
0-48-11	30.0	29.2	30.2	89.4	29.8 **
11-0-11	28.8	26.5	32.8	88.1	29.4
Check	25.8	25.5	28.0	79.3	26.4
	221.4	216.1	237.3	674.8	

Correction Factor $= \frac{(675.8)^2}{24} = 18970.31$

Total $S(x)^2 = 19300.06 - 18970.31 = \underline{329.75}$

Treatment $(Sx)^2 = \frac{57656.06}{3} = 19218.69 - 18970.31 = \underline{248.38}$

Reps $(Sx)^2 = \frac{152003.19}{8} = 19000.38 - 18970.31 = \underline{30.08}$

Table of Analysis for 1948

Variance	D.F.	S.Sq.	Mean Square	F.	1%	5%
Treatments	7	248.38	35.48	9.75 **	4.28	2.77
Reps	2	30.08	15.04	4.12 *	6.51	3.74
Error	14	51.29	3.65			

Minimum Significant Difference (treatments)

M.S.D. $= \frac{\sqrt{3.65} \times 2.83}{\sqrt{3}} = \frac{1.91 \times 2.83}{1.73} = \underline{3.12}$ lb. of ears per plot

Using check yield as standard

Check 26.41 ± 3.12 = 29.53
23.29

Therefore potassium 0-0-11 - 31.9 lb. per plot
phosphorus-potassium 0-48-11 - 29.8 lb. per plot
nitrogen 11-0-0 - 30.0 lb. per plot

are all significantly higher than check and phosphorus 0-48-0 - 20.6 lb. per plot significantly lower than check.

Part II

The Analysis for the 1947-49 Period with Sweet Corn

Table 1

Treatment

Years	Rep.	11-48-11	11-0-0	0-48-0	0-0-11	11-48-0	0-48-11	11-0-11	Check	Sum
1947	1	18.3	24.9	26.9	31.8	24.0	28.6	27.0	30.9	212.4
	2	25.9	26.6	22.9	17.2	27.2	27.7	17.6	18.2	183.3
	3	25.9	23.4	29.2	23.5	23.9	25.1	30.1	25.1	205.8
Totals		69.7	74.9	79.0	72.5	75.1	81.4	74.7	74.2	601.5
1948	1	28.8	30.0	22.5	28.0	27.5	30.0	28.8	25.8	221.4
	2	26.5	29.2	20.5	31.2	27.5	29.2	26.5	25.5	216.1
	3	31.0	31.0	18.8	36.2	29.0	30.2	32.8	28.0	237.3
Totals		86.3	90.2	61.8	95.7	84.0	89.4	88.1	79.3	674.8
1949	1	25.8	25.4	19.6	21.8	21.7	18.0	26.2	17.7	176.2
	2	23.6	25.8	20.0	24.4	21.6	17.7	22.8	19.6	175.5
	3	24.3	18.7	19.0	21.6	27.0	19.2	26.0	19.1	174.9
Totals		73.7	69.9	58.6	67.8	70.3	54.9	75.0	56.4	526.6

Table 2

Treatment

Year	11-48-11	11-0-0	0-48-0	0-0-11	11-48-0	0-48-11	11-0-11	Check	Sum
1947	69.7	74.9	79.0	72.5	75.1	81.4	74.7	74.2	601.5
1948	86.3	90.2	61.8	95.7	84.0	89.4	88.1	79.3	674.8
1949	73.7	69.9	58.6	67.8	70.3	54.9	75.0	56.4	526.6
	229.7	235.0	199.4	236.0	229.4	225.7	237.8	209.9	1802.9

Table 3

Years

Reps	1947	1948	1949	Sum
1	212.4	221.4	176.2	610.0
2	183.3	216.1	175.5	574.9
3	205.8	237.3	174.9	618.0
Total	601.5	674.8	526.6	1802.9

$$\text{Correction Factor} = \frac{(1802.9)^2}{72} = \frac{3250196.1}{72} = 45,141.61$$

$$\text{Total } S(x)^2 = 46317.53-45141.61 = \underline{1175.92}$$

$$\text{Treatment } (Sx)^2 = \frac{407576.17}{9} = 45286.24-45141.61 = \underline{144.63}$$

$$\text{Years } (Sx)^2 = \frac{1094376.31}{24} = 4559902-45141.61 = \underline{457.41}$$

$$\text{Treatment x Years } (Sx)^2 = \frac{138077.04}{3} = 46025.68-45141.61 = 884.07$$

$$= 884.07-(457.41 + 144.63) = \underline{282.03}$$

$$\text{Reps in general } (Sx)^2 = \frac{365498.99}{8} = 45687.35-45141.61 = 545.74$$

$$= 545.74-(457.41 + 43.61) = \underline{44.72}$$

Table of Analysis - 1947-49

Variance	D.F.	S.Sq.	Mean Square	F.	1%	5%
Treatment	7	144.63	20.66	1.02	4.28	2.77
Years	2	457.41	228.70	11.36 ¢¢	6.51	3.74
Reps in Gen.	6	44.72	7.45	1.26	3.26	2.32
Treat. x Yrs.	14	282.03	20.14	3.42 ¢¢	2.54	1.94
Error	42	247.13	5.88			

Part III

Pairing of Yields to Determine Effect of the Individual Elements of Sweet Corn

Three Year's Data Used

Effect of N

	N	No N		
	x	y	x-y	$(x-y)^2$
11-48-11 (x)	69.7	81.4	-11.7	136.8
0-48-11 (y)	86.3	89.5	-3.2	10.2
	73.7	54.9	18.8	353.4
11-48-0	75.1	79.0	- 3.9	15.1
0-48-0	84.0	61.8	22.2	492.8
	70.3	58.6	11.7	136.9
11-0-0	74.9	74.2	0.7	0.4
0-0-0	90.2	79.3	10.9	118.8
	69.9	56.4	13.5	182.2
11-0-11	74.7	72.5	2.2	4.8
0-0-11	88.1	95.7	- 7.6	57.8
	75.0	67.8	7.2	51.8
S	931.9	871.1	60.6	1561.0
M	77.6	72.6	5.0	

$$S^2 = \sqrt{\frac{\mathrm{I}\tfrac{1}{2}(1561.0)-\frac{(60.6)^2}{24}}{11}} = \sqrt{\frac{780.5-153.0}{11}} = \frac{627.5}{11} =$$

$$= \sqrt{57.04} = \underline{7.55}$$

$$t = \frac{5.05}{7.55} \times 3.45 = \underline{2.28} \text{ ¢}$$

t value for 11 degrees of freedom at 5% level is 2.201

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